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# NPOESS Risk Reduction, NAST for CrIMSS

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# NPOESS Risk Reduction, NAST for CrIMSS



**Dr. Bill Smith**

Professor, Hampton University &  
University of Wisconsin - Madison

- Department of Commerce  
Gold Medal Award
- AMS Meissinger Award
- AMS Verner E. Suomi Award
- AMS Remote Sensing Lecturer
- Fellow, AMS





# NPOESS Risk Reduction, NAST for CrIMSS

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<sup>3</sup>NASA Langley Research Center

<sup>4</sup>NPOESS Integrated Program Office

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# Acknowledgements

**IPO for NPOESS:** Programmatic responsibility and guidance of the implementation of the NPOESS Airborne Sounder Testbed (NAST) instruments, the Crosstrack Infrared Sounder (CrIS), and the Advanced Technology Microwave Sounder (ATMS)

**UW-SSEC and MIT-LL:** Provider of Scanning HIS (S-HIS) and NAST-Interferometer (NAST-I), respectively, for validating CrIMSS measurement concepts, CrIS engineering oversight, analysis of CrIS EDU data

**MIT:** Provider of NAST-Microwave (NAST-M) spectrometer for validating ATMS measurement concepts, and for the processing & analysis of NAST-M data

**NASA LaRC and University of Wisconsin:** Field deployment and science processing and analysis of the NAST / S-HIS data to validate CrIS SDRs, EDR algorithms, and EDR products

**ITT and Aerojet:** Design, development, implementation, and testing of the CrIS and ATMS instruments, respectively, that form the CrIMSS

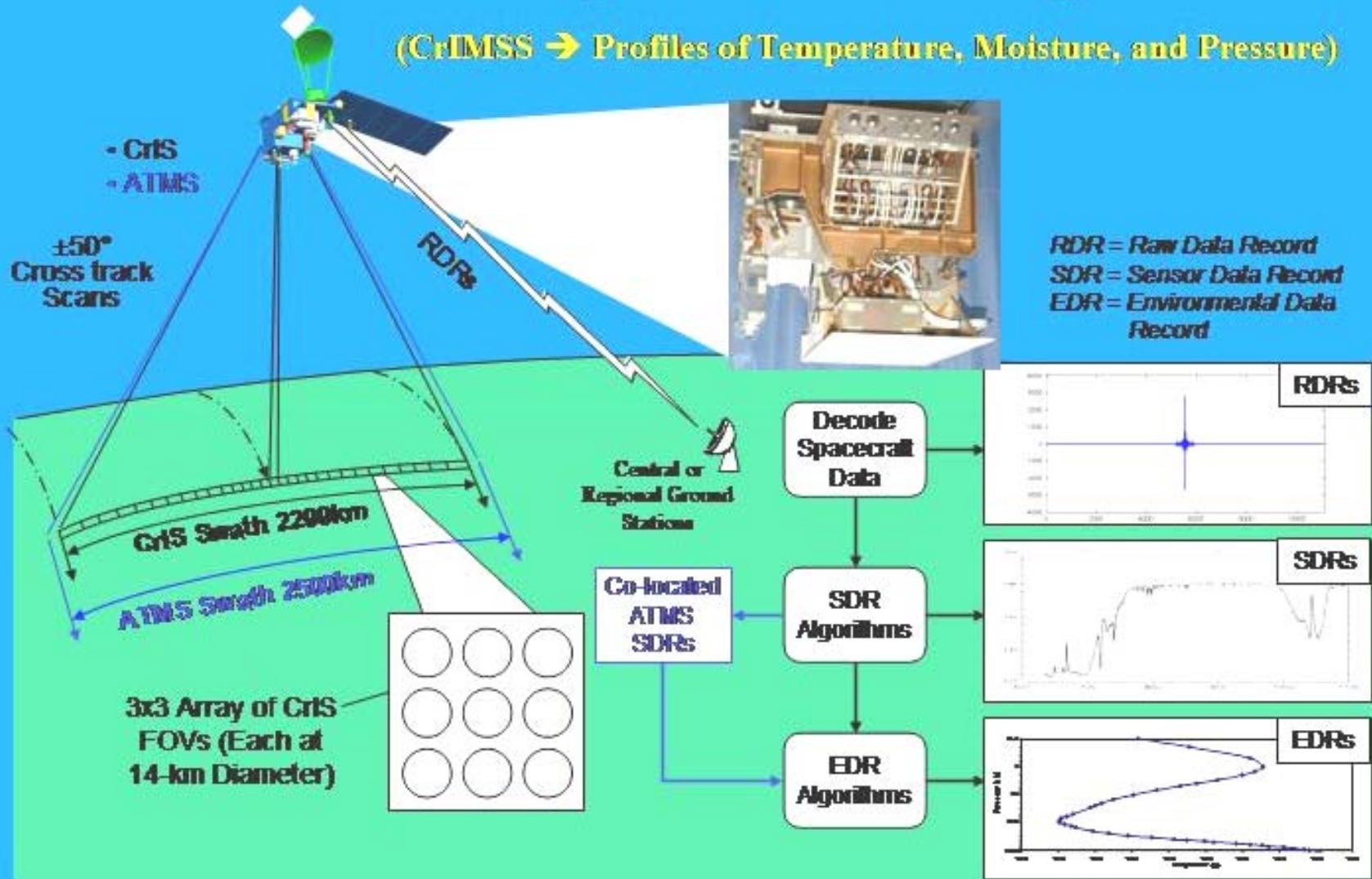
**AER:** Development of Baseline CrIMSS EDR software

**NGST and Raytheon:** NPOESS CrIMSS Hardware / Software system



# CrIMSS - CrIS & ATMS Combined to Provide Sounding EDRs

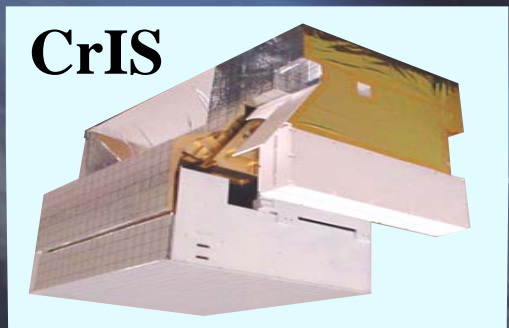
(CrIMSS → Profiles of Temperature, Moisture, and Pressure)



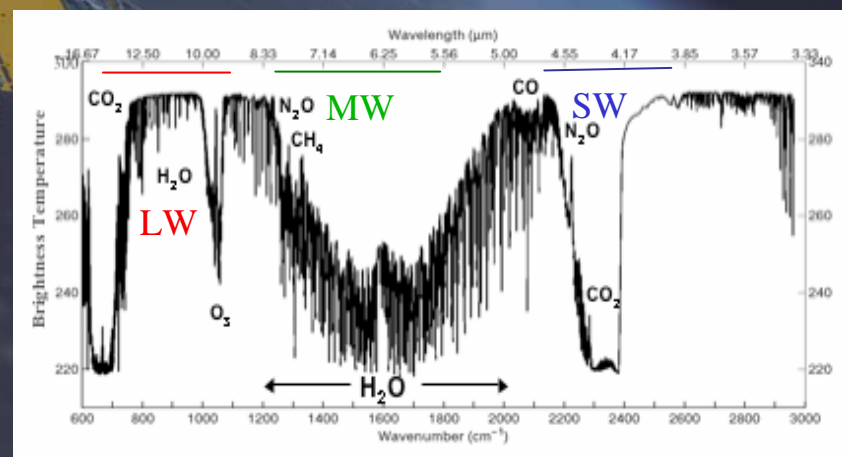
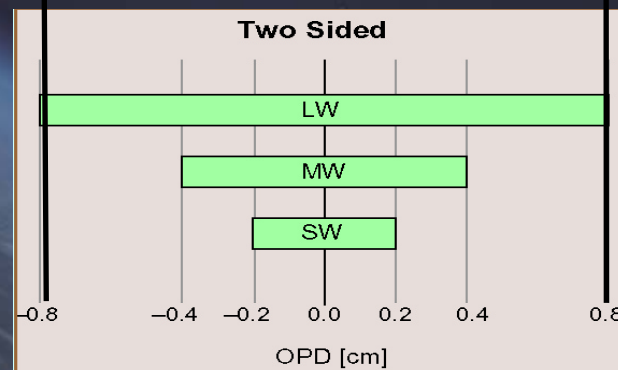
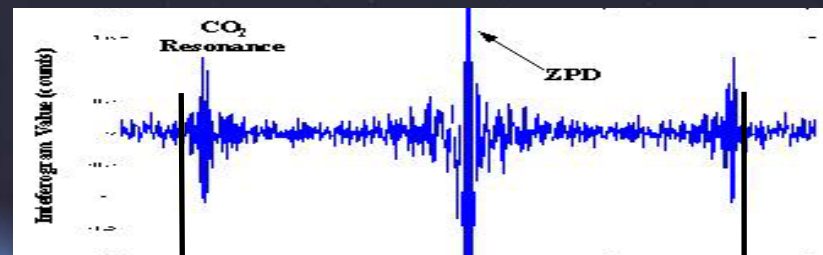


# Cross-track Infrared Sounder (CrIS)

## A Precision Infrared Interferometer Spectrometer

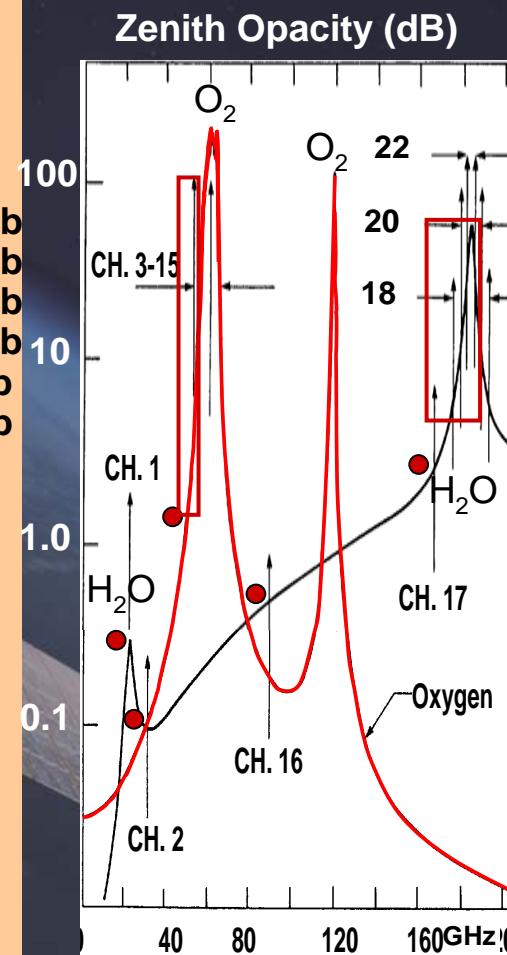
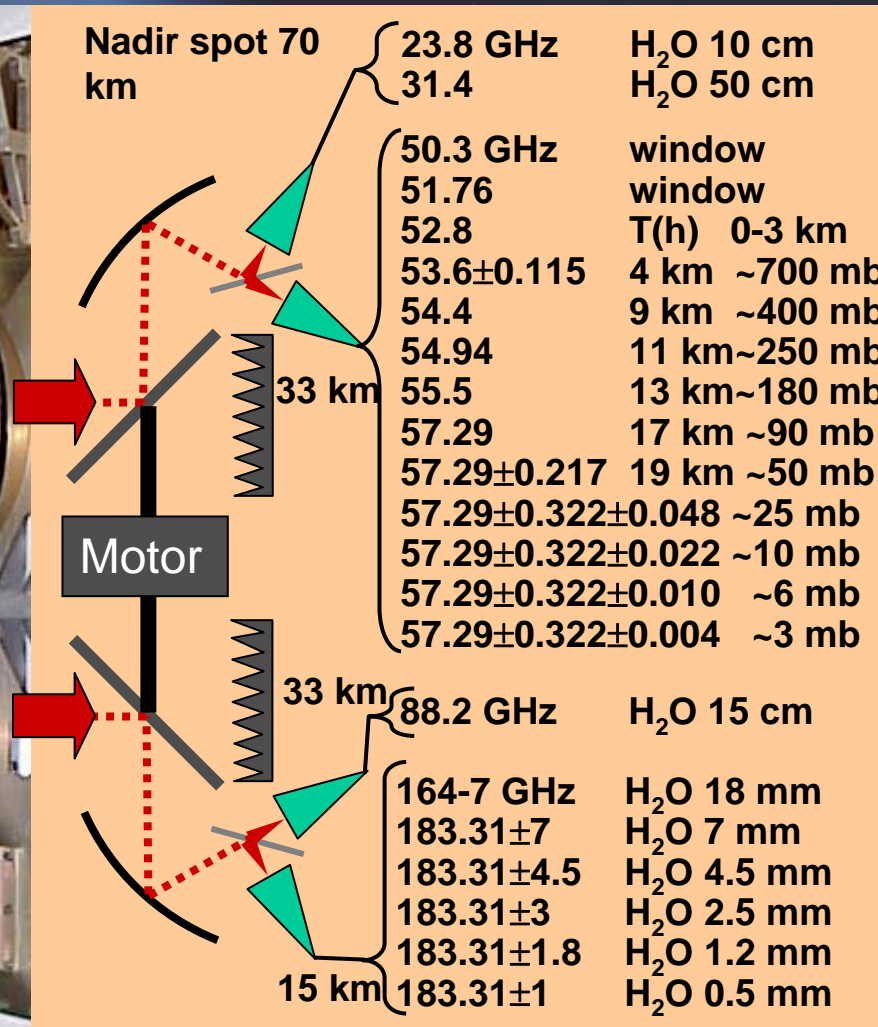
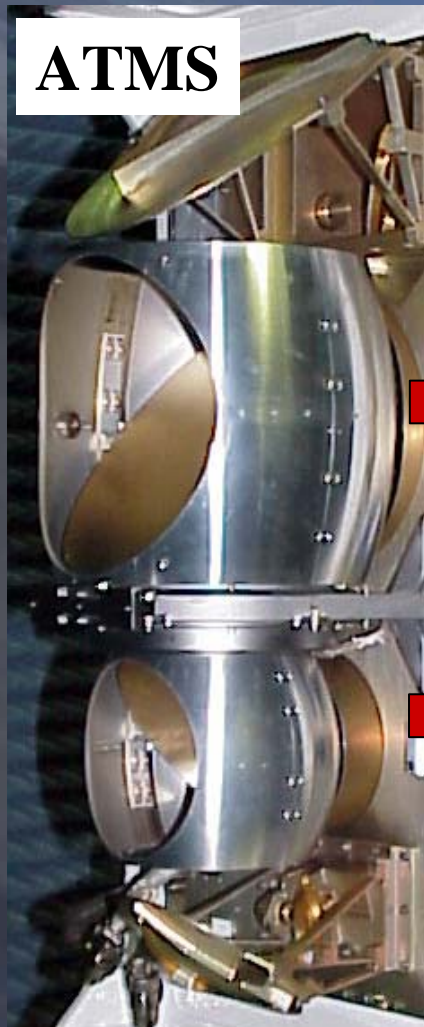


- Michelson Interferometer (FTS)
- Large 8 cm Clear Aperture
- Three Spectral Bands
  - LWIR: 650-1095  $\text{cm}^{-1}$  (713 Chan)
  - MWIR: 1210-1750  $\text{cm}^{-1}$  (433 Chan)
  - SWIR: 2155-2550  $\text{cm}^{-1}$  (159 Chan)
- 1305 Total Spectral Channels
- 3x3 FOVs at 14 km Diameter for each Band
- Photovoltaic Detectors in All 3 Bands
- 4-Stage Passive Detector Cooler (81K)
- Plane-Mirror Interferometer With DAPS
- Internal Laser Wavelength Calibration
- Deep-Cavity Internal Calibration Target



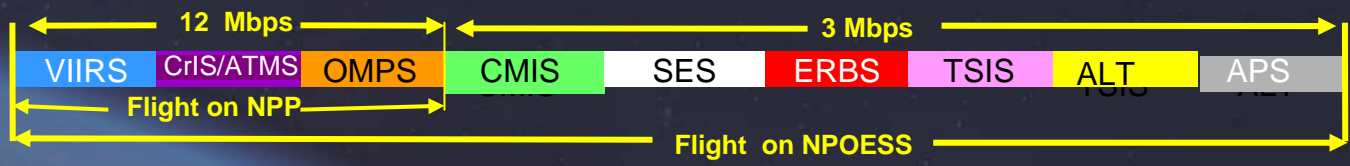


# Advanced Technology Microwave Sounder (ATMS) A 22 Channel High Resolution (16 - 32 km) Radiometer





# CrIMSS Contributes to 24 Measurement Objectives



★ Atmospheric Vertical Moisture Profile	Cloud Top Pressure	Precipitable Water
★ Atmospheric Vertical Temp Profile	Cloud Top Temperature	Precipitation Type/Rate
★ Imagery	Downward Longwave Radiance (Sfc)	Pressure (Surface/Profile)
★ Sea Surface Temperature	Downward Shortwave Radiance(Sfc)	Sea Ice Characterization
★ Sea Surface Winds	Electric Field	Sea Surface Height/Topography
★ Soil Moisture	Electron Density Profile	Snow Cover/Depth
Aerosol Optical Thickness	Energetic Ions	Solar Irradiance
Aerosol Particle Size	Geomagnetic Field	Supra-Thermal-Auroral Particles
Aerosol Refractive Index	Ice Surface Temperature	Surface Type
Albedo (Surface)	In-situ Plasma Fluctuations	Wind Stress
Auroral Boundary	In-situ Plasma Temperature	Suspended Matter
Auroral Energy Deposition	Ionospheric Scintillation	Total Water Content
Auroral Imagery	Medium Energy Charged Particles	Vegetation Index
Cloud Base Height	Land Surface Temperature	
Cloud Cover/Layers	Net Heat Flux	
Cloud Effective Particle Size	Net Solar Radiation (TOA)	
Cloud Ice Water Path	Neutral Density Profile	
Cloud Liquid Water	Color/Chlorophyll	
Cloud Optical Thickness	Ocean Wave Characteristics	
Cloud Particle Size/Distribution	Outgoing Longwave Radiation (TOA)	
Cloud Top Height	Ozone - Total Column/Profile	

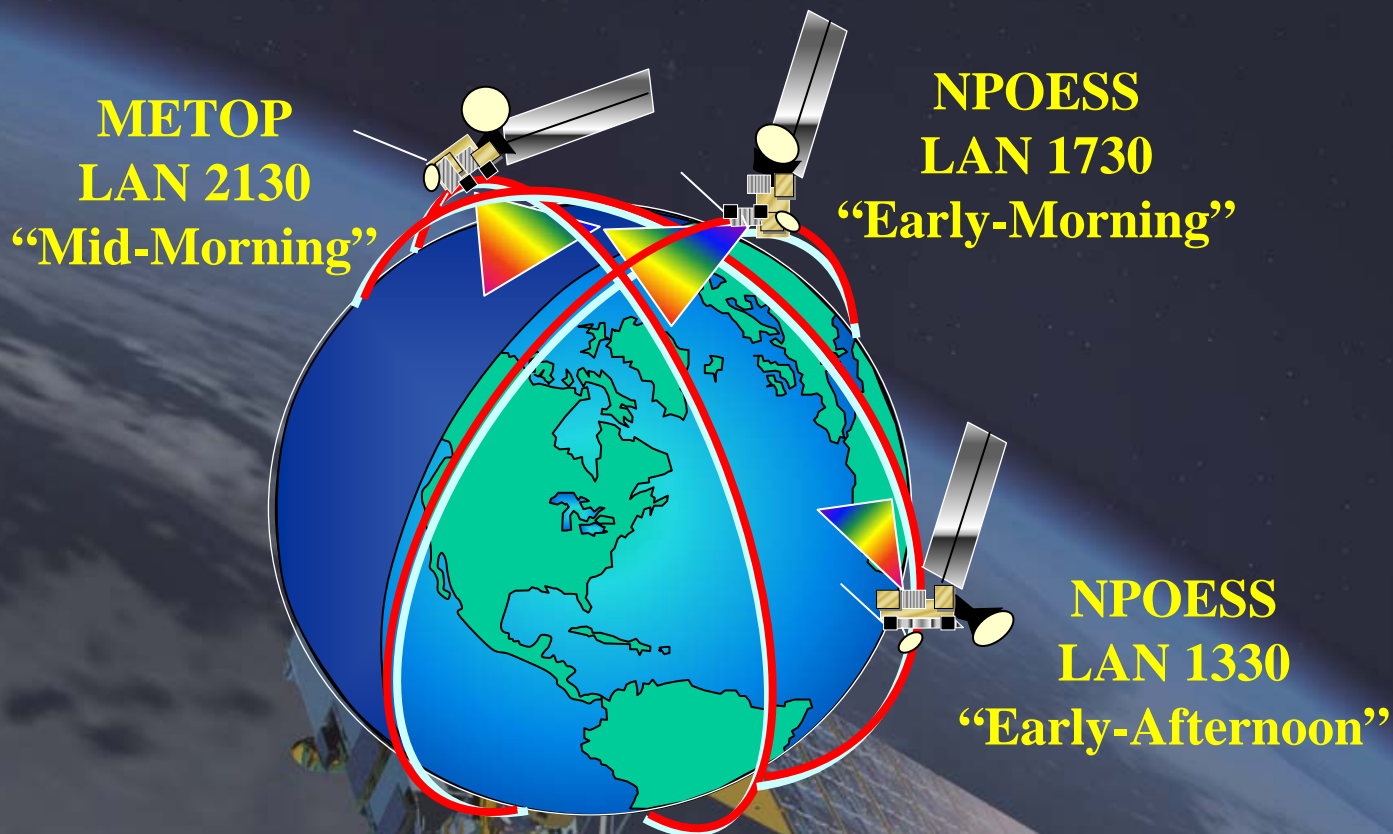
	VIIRS (23)
	CMIS (19)
	CrIS/ATMS (3)
	OMPS (1)
	SES (13)
	ERBS (5)
	TSIS (1)
	ALTIMETER (3)
	APS (4)

**CrIMSS(24)**

★ Environmental Data Records (EDRs) with Key Performance Parameters



# NPOESS & METOP Together Provide 4-Hour Coverage [ METOP to be launched this coming June 2006 ! ]



Sounders	Lifetime (# Satellites)	Atmos Sounders
METOP [2130]	5 yr (3 satellites)	IASI/AMSU/MHS
NPOESS [1330]	7 yr (2 satellites)	CrIS/ATMS
NPOESS [1730]	7 yr (2 satellites)	CrIS/ATMS



# NAST Airborne Calibration/Validation System Enables Precise Cal/Val of SDRs, Algorithms, & EDRs

[NASA/LaRC, U. Wisconsin, MIT Lincoln Laboratory, MIT]

## OBJECTIVES

- Developed by IPO to Simulate Candidate Spaceborne Instruments - CrIS, ATMS, IASI, AIRS, AMSU, HSB
- Science Issue & Risk Reduction Testbed
- Evaluate Key EDR Algorithms
- Preview High Resolution Products (Spectral & Spatial)
- Under Flight Calibration/Validation [AIRS, IASI, CrIS, AMSU, HSB, ATMS]

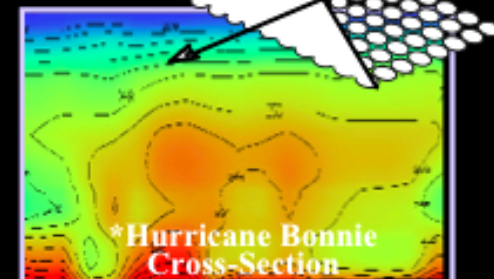
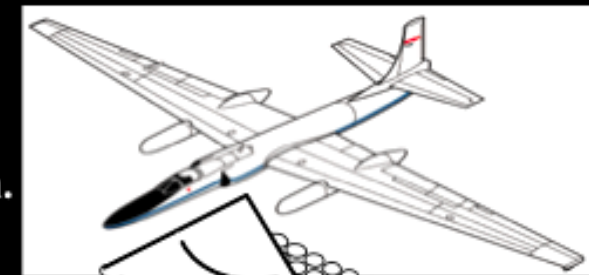
## INSTRUMENTS [NAST-I & NAST-M]

- NAST-I: IR Michelson Interferometer [FTS] Sounder
- NAST-M: Microwave Sounder
- Co-Boresighted IR and Microwave
- IR Interferometer [FTS] Sounder 3.5 – 16  $\mu\text{m}$ , 9000 Chan.
  - High Spectral Resolution 0.25  $\text{cm}^{-1}$
  - Calibrated Radiances-0.5K Abs. Accuracy, 0.1K Prec.
  - High Sensitivity in a cold scene
    - 0.10 K NEDT @ 14.9  $\mu\text{m}$  (250K)
    - 0.15 K NEDT @ 8.2  $\mu\text{m}$  (250K)
    - 0.20 K NEDT @ 4.7  $\mu\text{m}$  (250K)
- Microwave Sounder  
[4 Bands, 29 Chan.] 50-56, 118.7 $\pm$ 4, 183 $\pm$ 11, 425 $\pm$ 4 GHz



NAST on ER-2

At 20 km ALTITUDE  
NADIR 2.6 km IFOV  
 $\pm 23$  km GROUND COVERAGE  
 $\pm 48^\circ$  Scan





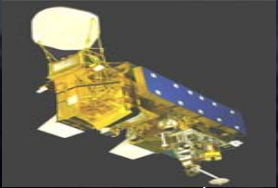
# Purpose of NAST

- The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Airborne Sounder Testbed (**NAST**) program **was established to provide** *experimental data needed to:*
  - (1) **validate the design of the satellite sensors**
  - (2) **develop** data processing **algorithms**, and
  - (3) **provide precise, and early, radiance data for validating and improving the calibration of the scientific observations** (i.e., SDRs and EDRs) obtained from the space deployment of the sounders
  - (4) **investigate the observation of other important surface and atmospheric composition variables** (e.g., surface temperature and emissivity, precipitation cell height, atmospheric aerosol and dust plumes, cloud microphysical and geometric properties, and trace gases such as  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ,  $\text{SO}_2$ ,  $\text{O}_3$ , which might be extracted from CrIS and ATMS data
  - (5) **provide validation of data products from heritage satellite sounders** (e.g. HIRS/AIRS/IASI/CrIS, AMSU/MHS/HSB/ATMS) to NPOESS/NPP users **for NPOESS readiness preparation and for development of improvements in weather and climate forecasting**



# NAST Provides Precise Cal/Val Data in Support of Near Real-Time Operational Demonstrations of the Utilization of Advanced Sounder Data for Numerical Weather Prediction

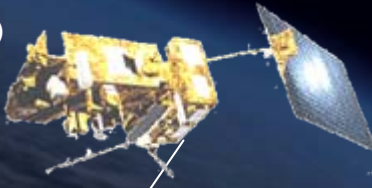
**“Aqua” [EOS-PM] (2002)**  
**AIRS/AMSU/HSB & MODIS**



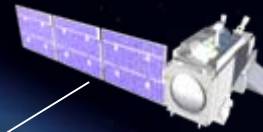
**WindSat (2003)**



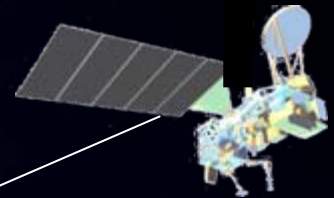
**METOP (2006)**  
**IASI/AMSU/MHS, GOME-2 & AVHRR**



**NPP (2009)**  
**CrIS/ATMS, OMPS & VIIRS**



**NPOESS**  
**CrIS/ATMS, VIIRS, CMIS, OMPS, ERBS, APS**



## NOAA Near Real-Time Data Delivery Ground Station Scenario

**C3S**

**IDPS**

**NOAA  
Realtime  
User**

**NWS/NCEP  
GSFC/DAO  
ECMWF  
UKMO  
FNMOC  
Meteo-France  
BMRC-Australia  
Met Serv Canada**

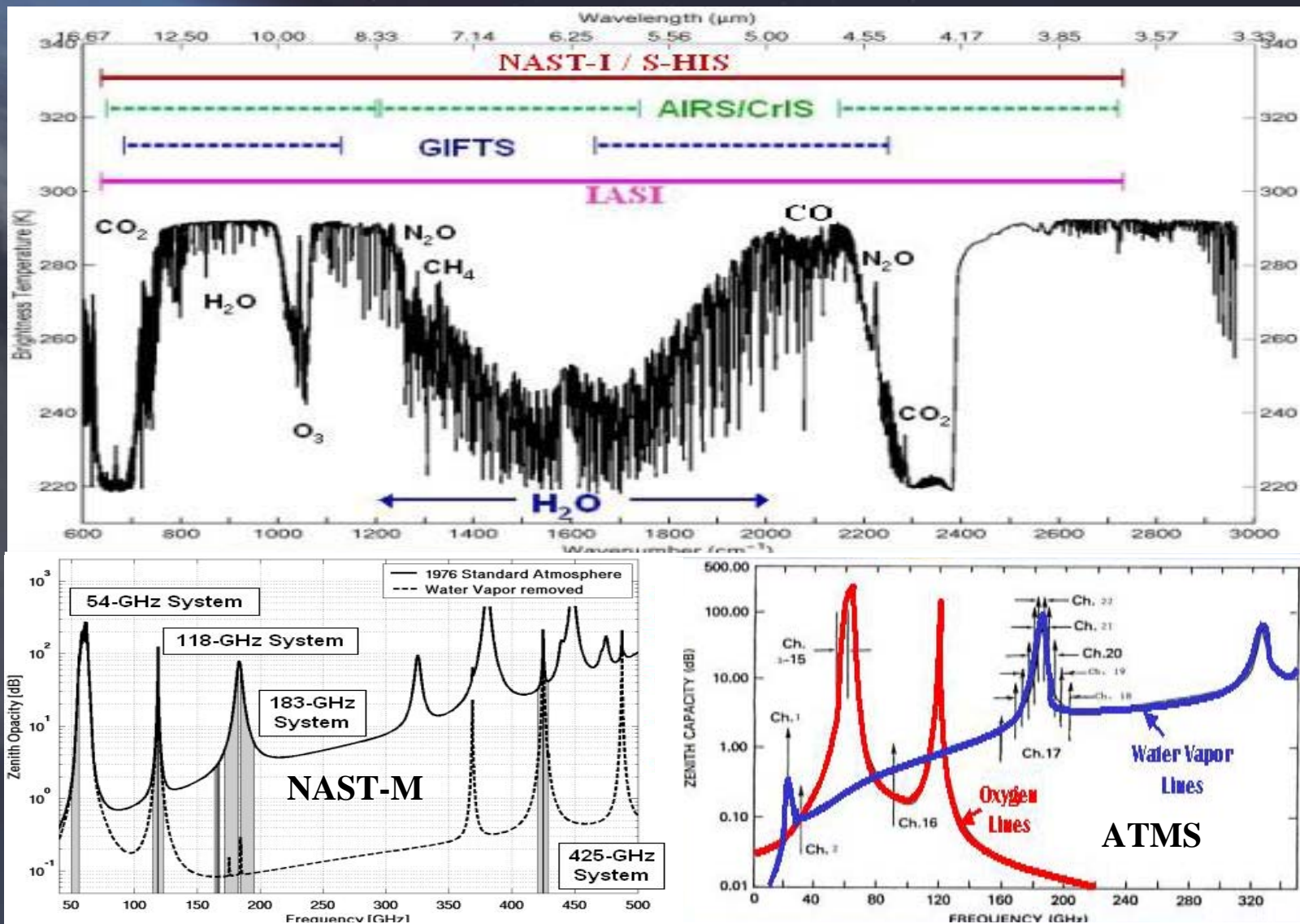
**NWP  
Forecasts**

**Joint Center for Satellite Data Assimilation**



# NAST Spectral Characteristics

## Coverage Overlaps Future IR & MW Sounders





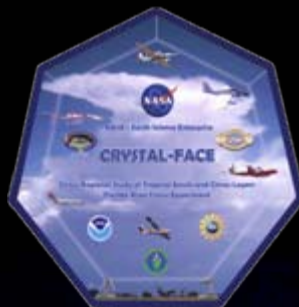
# NAST

Has Flown in 17 Cal/Val Campaigns (>850 hrs)

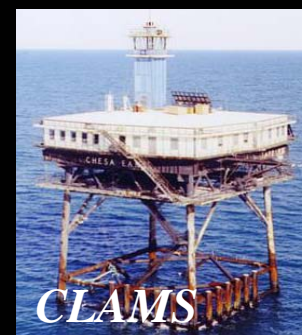
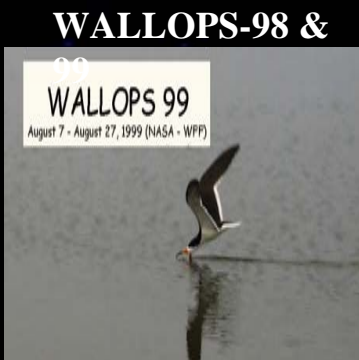
NPOESS/NPP Cal/Val Agency Participants [IPO,NASA, NOAA, DOE, DoD, NSF]



ER-2



Proteus



NAST has flown ~ 152 mission sorties accumulating over 850 hours of flight data in 17 field experiments:

Wallops98 (June-July, 1998); CAMEX-3 (Aug-Sep, 1998); WINTEX (Mar, 1999); Wallops99 (Aug, 1999); C-IOP (Mar, 2000), WV-IOP (Sep-Oct, 2000); AFWEX (Nov-Dec, 2000); Asian-Pacific (Feb-Mar, 2001); CLAMS (Jul-Aug, 2001); IHOP (May-Jun, 2002), CRYSTAL-FACE (Jul, 2002), TX2002 (2002), TOST (Feb-Mar, 2003), THORPEX 2003, INTEX (2004), EAQUATE-1 (2004), EAQUATE-2 (2004)





# CrIMSS Calibration/Validation Approach

## Airborne Obs. Enable Precision Cal/Val

### Spatial

- Landmark navigation
  - compare observations for time invariant features of known spatial characterization (e.g., coastlines)
- Comparison with coincident observations
  - compare measurements with temporally-coincident same-scene view observations (e.g., NAST)

### Spectral

- Comparison with simulations
  - compare clear sky measured radiance to radiative transfer model calculations for spectral regions where Forward model parameters are well-known
- Comparison with coincident observations
  - compare measured radiance with other temporally-coincident same-scene view high-spectral resolution measurements (e.g., NAST/SHIS)

### Radiometric

- Comparison with other coincident observations and simulations
  - High-spectral resolution measurements (e.g., NAST/SHIS)
  - Broadband radiance measurements (e.g., MAS, GOES, SEVERI, MODIS, VIIRS, AMSU)
  - Radiative transfer calculations (using, e.g., lidar, radiosondes, dropsondes)



# Inter-comparison Summary:

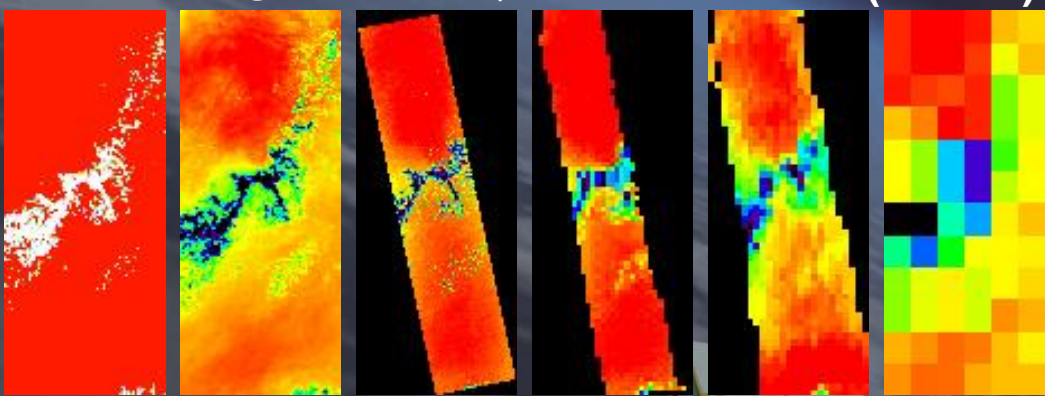
## NAST is used for Spatial, Radiometric, & Spectral Cal/Val of Aqua

Geo-reference verification using like spatial features;  
shows clear regions used for spectra inter-comparison

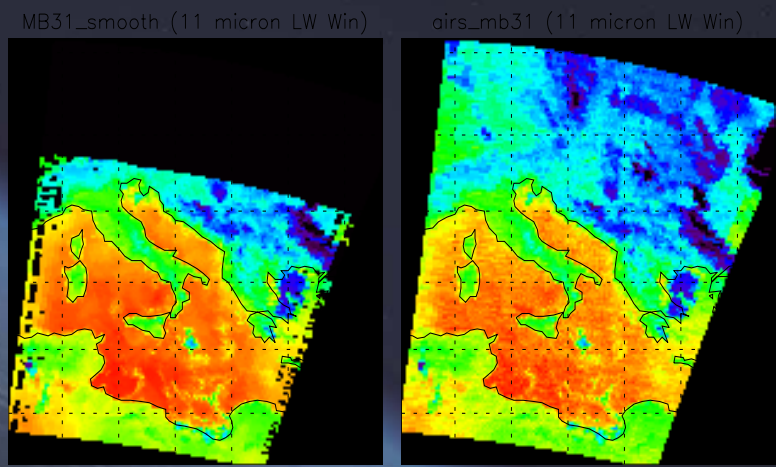
EAQUATE (090904)

Window region (MB31; 11 $\mu$ )

PTOST (030303)



MODIS (Cld msk)    MODIS    MAS (B45)    S-HIS    NAST-I    AIRS

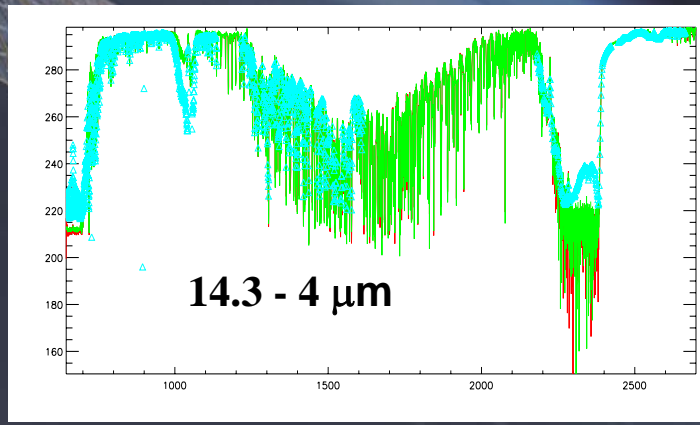
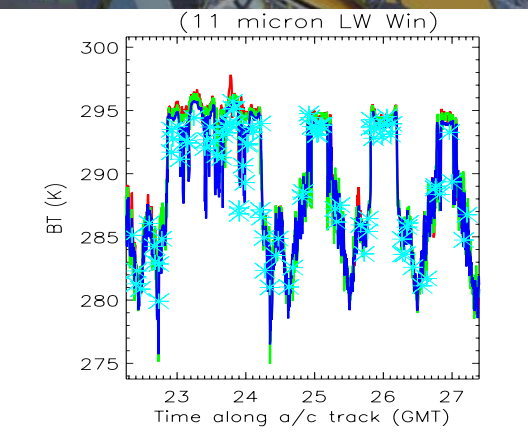
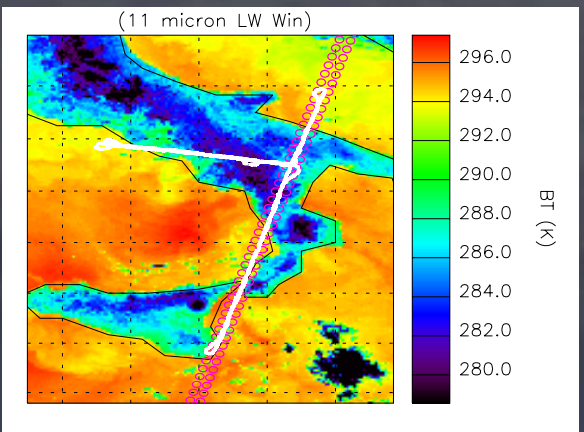


MODIS Vs AIRS  
(Via Spectral & Spatial Convolution)  
(MB31 srf/ AIRS IFOVs)

Aqua & Proteus ground tracks

Broadband radiometric time series

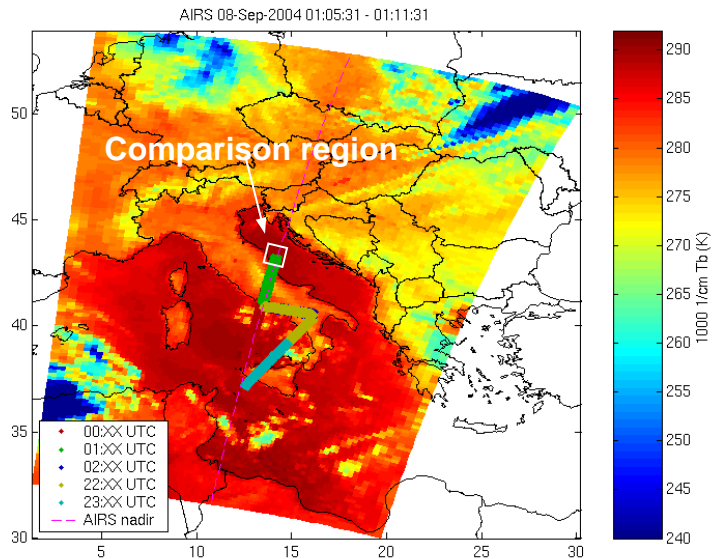
NAST-I, S-HIS, & AIRS spectra



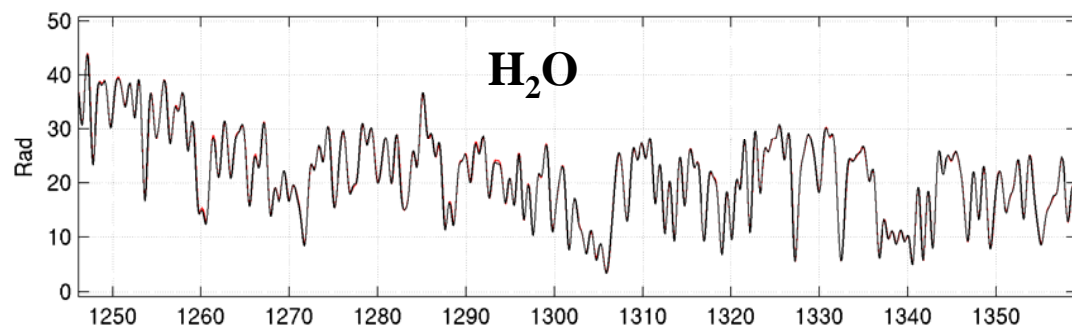
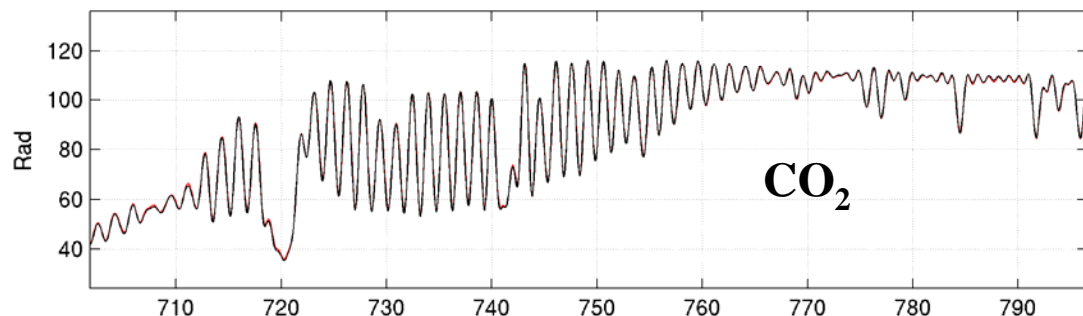
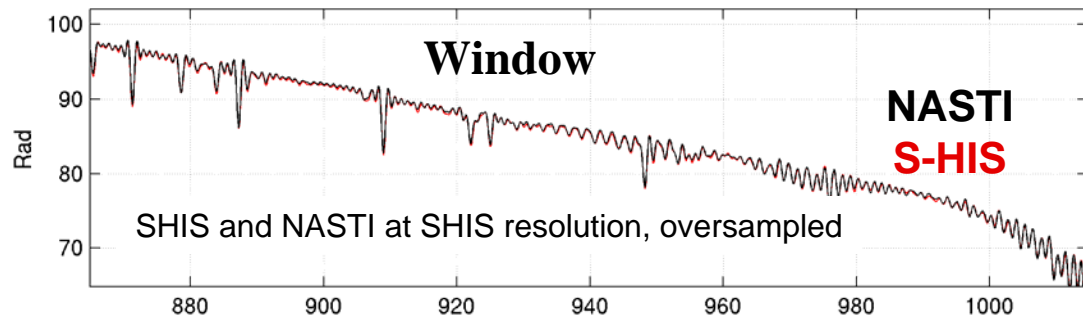


# Radiance Measurement Validation ( SHIS vs. NAST-I ) Provide In-flight Calibration Validation

**07 Sep 2004  
EAQUATE Italy**



**S-HIS flight track overlaid on  
AIRS 1000  $\text{cm}^{-1}\text{Tb}$  image**

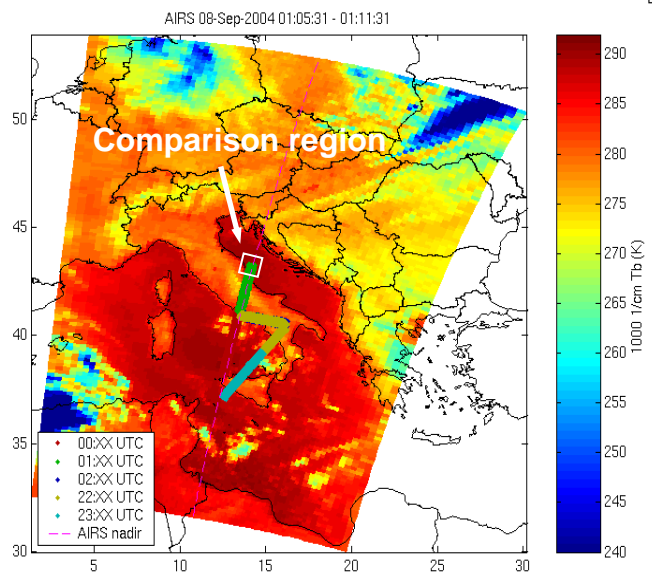




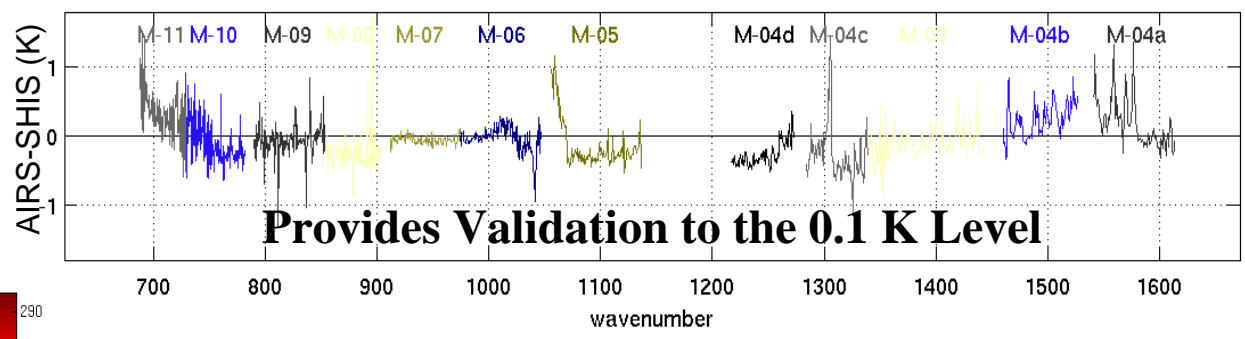
# Radiance Measurement Validation

## SHIS vs. AIRS - Reveals Small Errors in AIRS Calibration

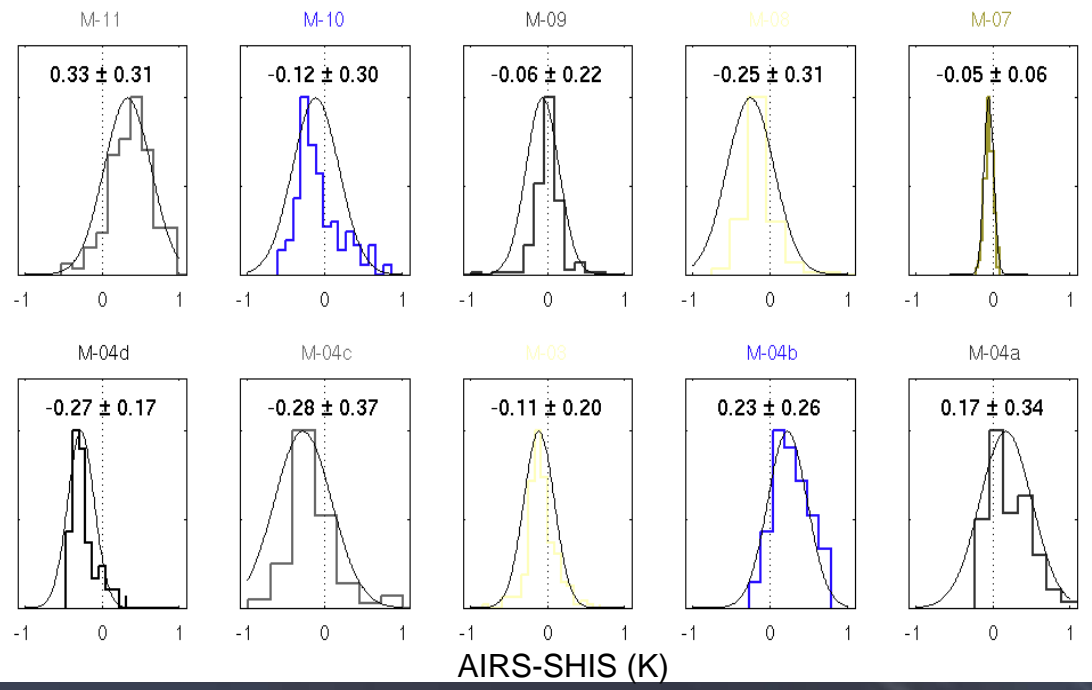
**07 Sep 2004**  
**EAQUATE Italy**



**S-HIS flight track overlaid on  
AIRS 1000 cm<sup>-1</sup>Tb image**



**Provides Validation to the 0.1 K Level**





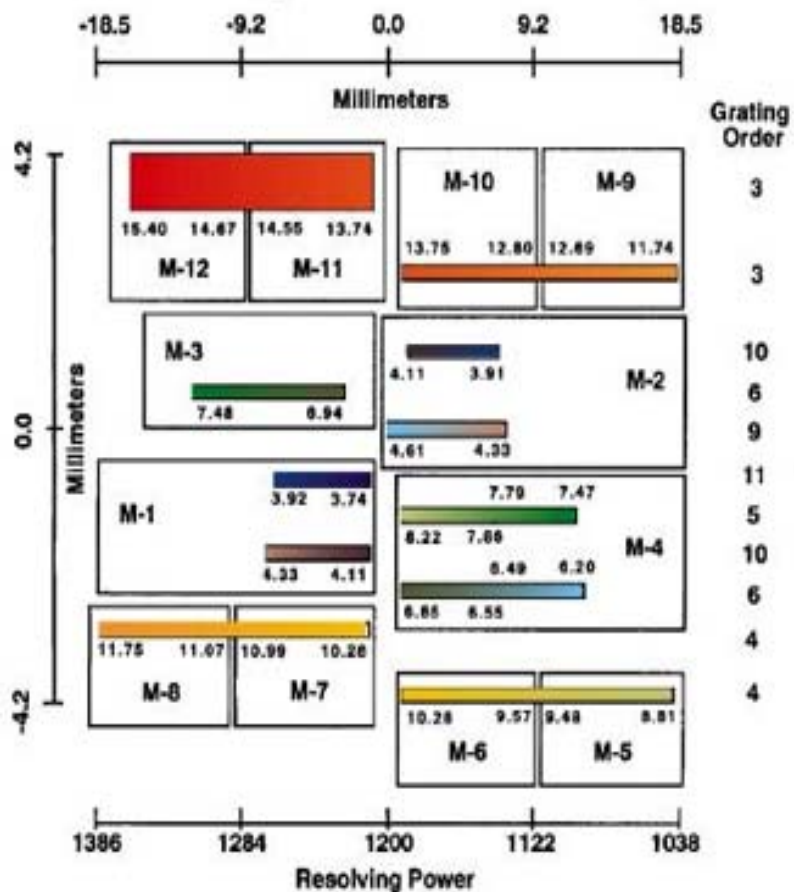
# Spectral Validation ( SHIS Vs AIRS ) :

## Reveals Spectral Shift of 3% of resolution element in AIRS Module-05 Detector Array

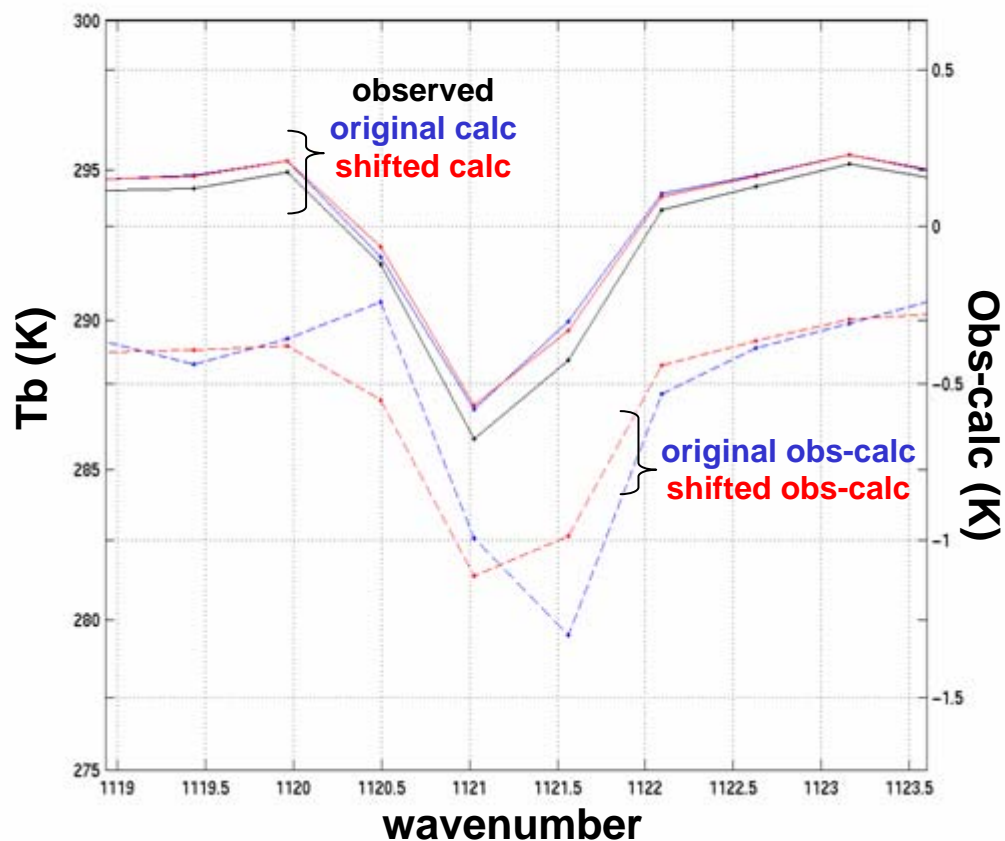
AIRS



Focal Plane Color Map



S-HIS Spectral Calibration Accuracy presented by Tobin et al., CALCON 2003

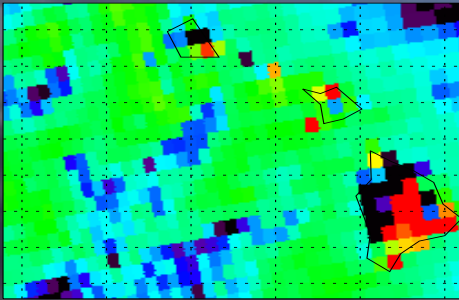




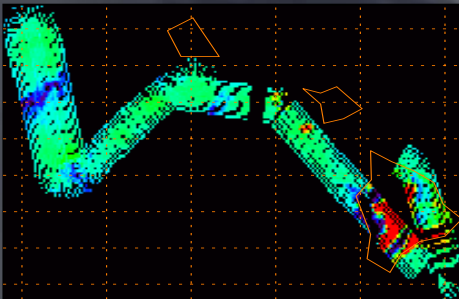
# Spectral Validation ( NAST-I vs. AIRS ) : Reveals AIRS Spectral Anomalies Produced By Detector Spatial Misregistration

## MODIS Band 32 or Equivalent

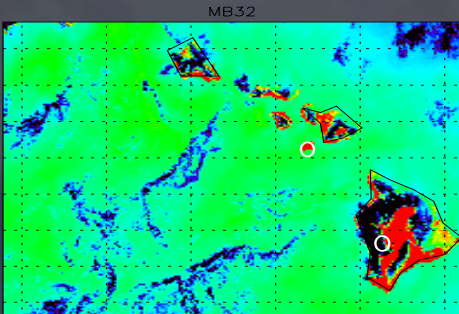
AIRS



NAST-I



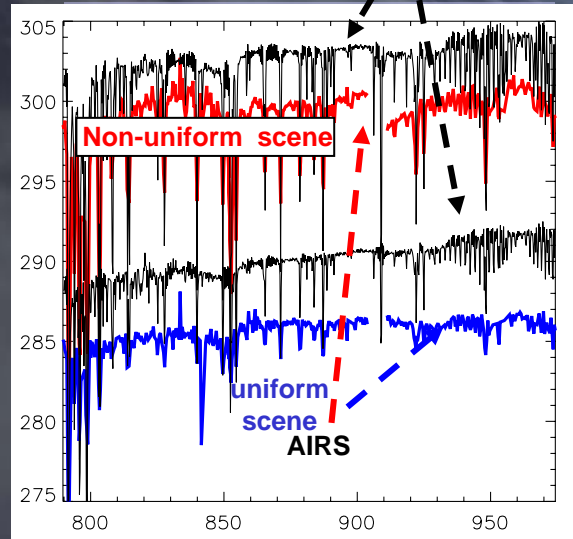
MODIS



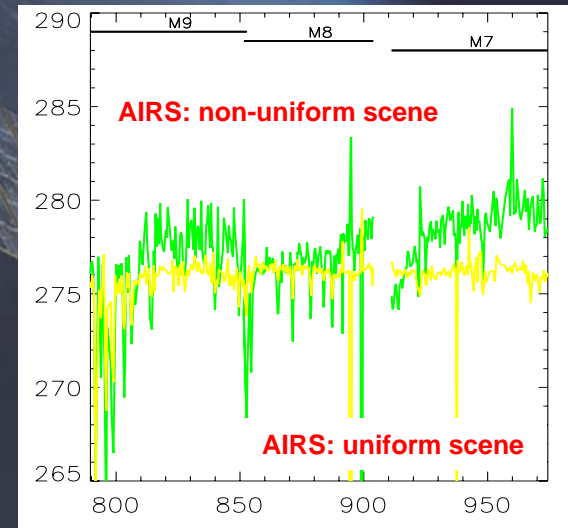
- Spectra for uniform & non-uniform scenes shown for two different days
- NAST-I in black; AIRS in colors
- Spectral extent of 3 AIRS detector modules also shown for reference (091404 case)

03 03 2003

NAST-I



09 14 2004





# Forward Model Validation : CrIS Forward Radiative Transfer Model Comparisons with NAST-I Spectra

## **NAST-I radiance is ideal for CrIS forward model validation**

- Both CrIS and NAST-I are FTIR instruments
- High spectral resolution
  - Can generate accurate CrIS proxy data from NAST-I
- Good absolute calibration
- High quality ground truth

## **NAST RT model has the same parameterization as CrIMSS**

- Physical parameterization
- Works with variable aircraft altitudes
- Used in NAST-I retrieval algorithm without bias correction

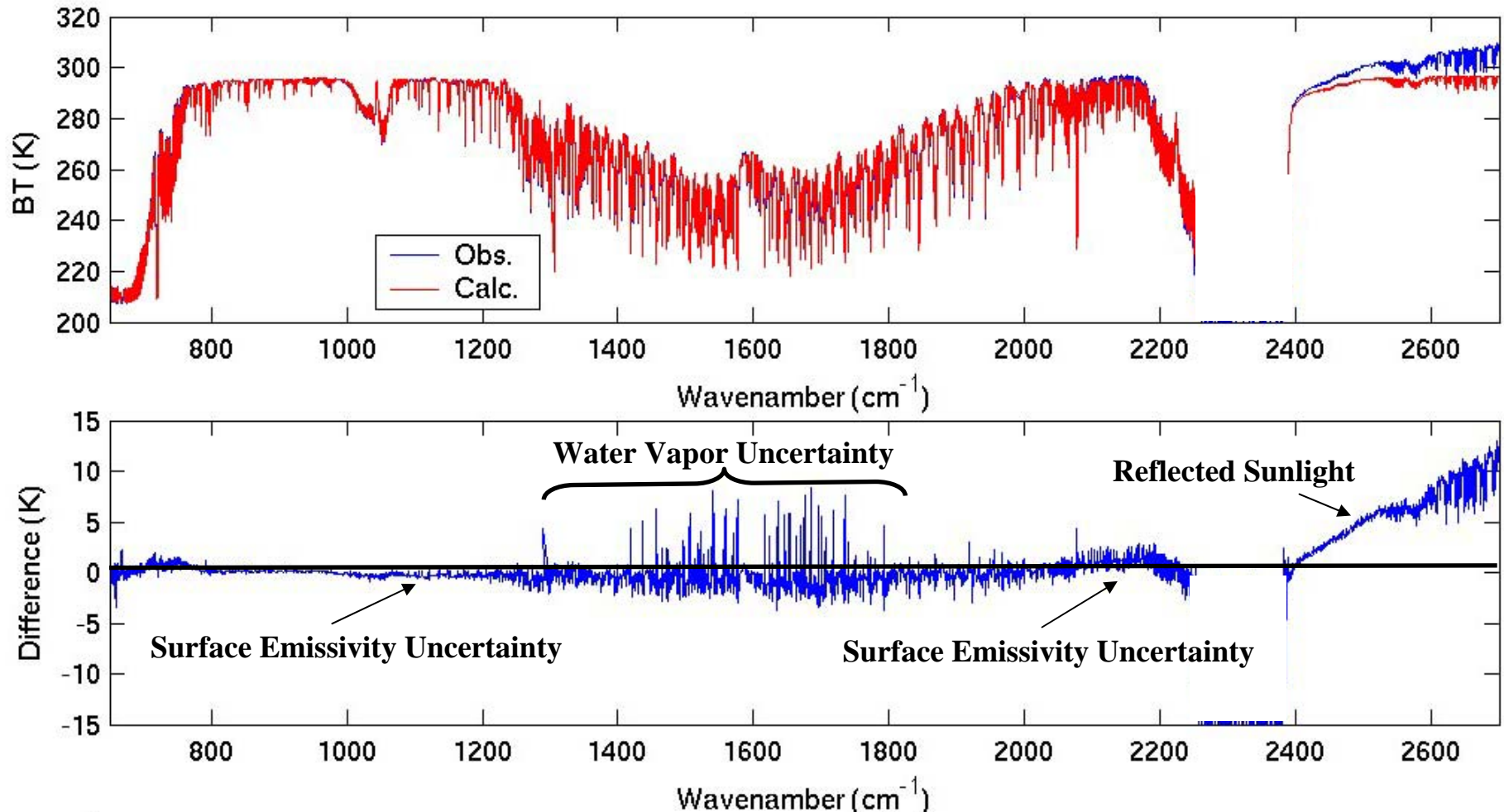
## **New NAST-based RT developments for risk reduction**

- Cloud modeling
  - With multiple scattering effect considered
  - Enable single FOV retrieval in the presence of clouds
- Super fast RT models based on principal component analysis (PCRTM)
  - A factor 30 faster than baseline RT model
  - Enable use of all the information content
  - Enable multiple FOV retrievals without increasing computational time



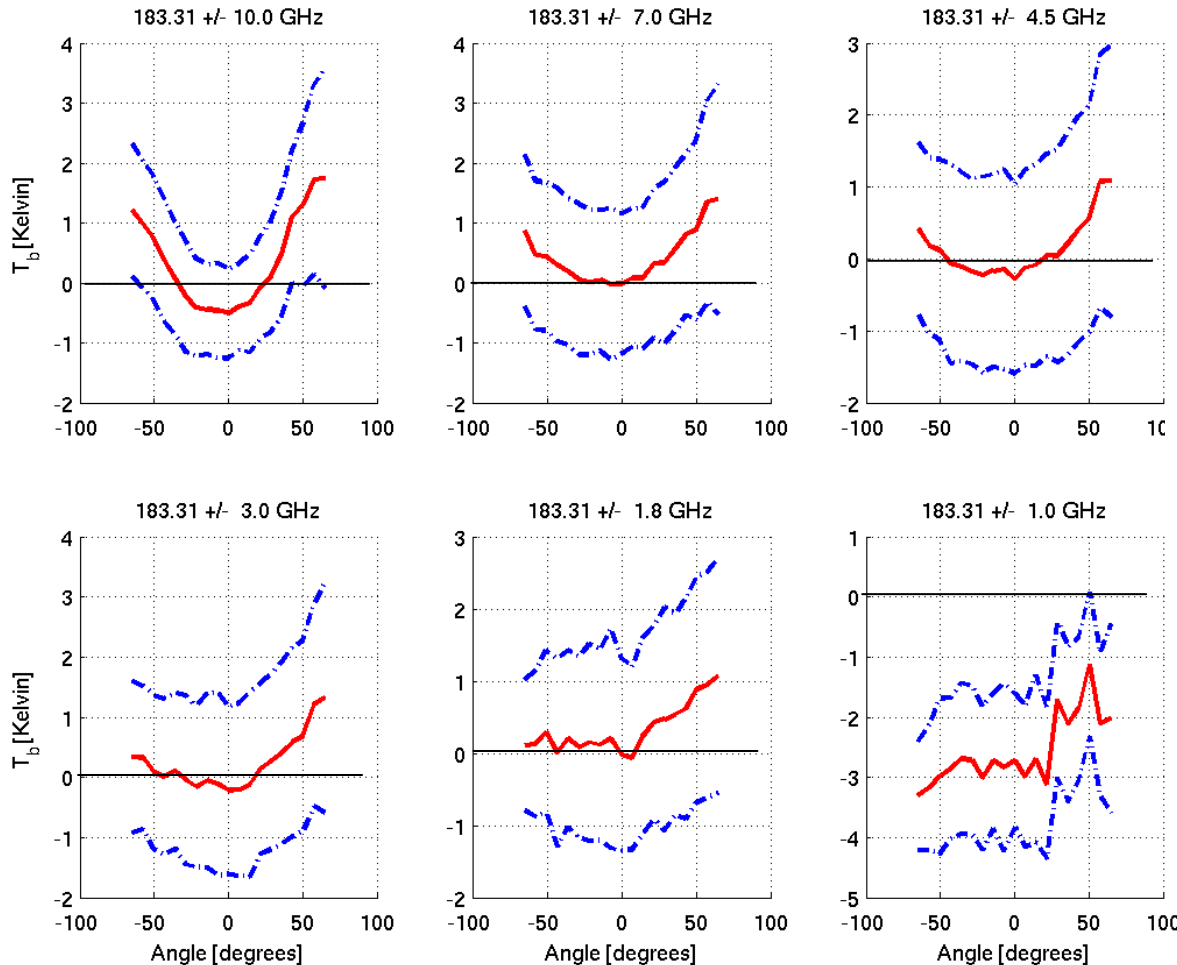
# Forward Model Validation : NAST-I Validates New CrIS Fast Forward Radiative Transfer Model ( PCRTM )

## NAST-I Observation Vs Radiosonde PCRTM Calculation





# Forward Model Validation : NAST-M Validates ATMS 183 GHz Channel Radiative Transfer Model



- A set of thirteen dropsonde profiles
  - Distance apart: 0.15-40 km
  - Time difference: 1-36 min.
  - Three days during the THORpex 2003 deployment
  - 3-pt Calibration
- Red = mean**  
**Blue = one standard deviation away from mean**



# PTOST

## An Aqua AIRS/AMSU Cal/Val Campaign

**PTOST** (February 18 - March 13, 2003, HAFB, Hawaii). The 2003 Pacific *THORPEX Observing System Test (TOST)* was the first in a series of Pacific and Atlantic observation campaigns in support of the WWRP/USRP THORPEX Program. THORPEX - a Global Atmospheric Research Program aimed at improving short range (up to 3 days), medium range (3-7 days) and extended range (two week) weather predictions. Flights targeted frontal boundaries and storm systems, as well as satellite sensor validation underflights (TERRA, AQUA, and ICESat)

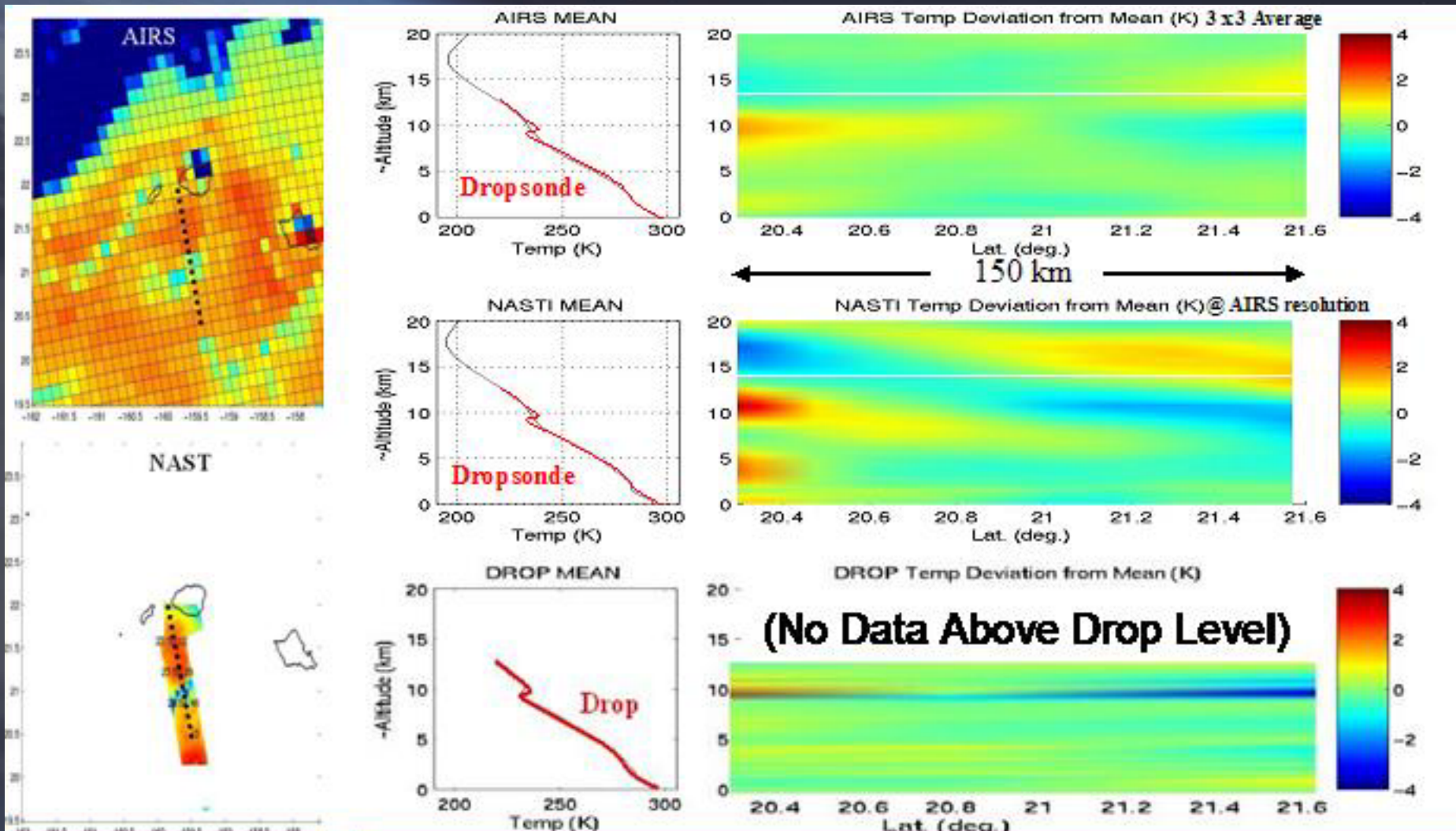
### Aircraft Sensors Included:

**ER-2** (NAST-I, NAST-M, S-HIS, MAS, CPL); **G-IV** (Dropsondes, in-situ O<sub>3</sub>)





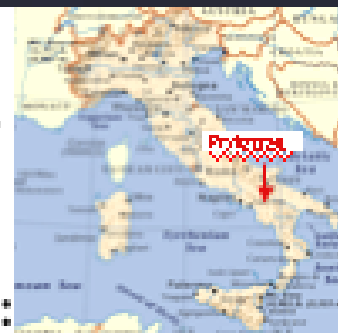
# EDR Validation : NAST and Dropsondes Show That Noise Reduced ( 3x3 ) AIRS Radiances Capture Vertical Structure





# EAQUATE Italian Cal/Val Campaign

**EAQUATE (European AQUA Thermodynamic Experiment)-**  
*A project to validate radiance and geophysical products obtained by the Atmospheric Infrared Sounder (AIRS) aboard the Aqua satellite*



## Italian Campaign (Naples It., Aug. 30 – Sept. 9, 04):

- **US *Proteus* Aircraft**



*NAST-I*: 3.6-16  $\mu\text{m}$ , 0.25  $\text{cm}^{-1}$   
*NAST-M*: 50-425 GHz (29  $f's$ )  
*S-HIS*: 3.0-17  $\mu\text{m}$ , 0.50  $\text{cm}^{-1}$   
*FIRSC*: 75-1000  $\mu\text{m}$ , 0.1  $\text{cm}^{-1}$   
 *$\mu$ MAPS*: 4.5-4.9  $\mu\text{m}$ , (3  $f's$ )

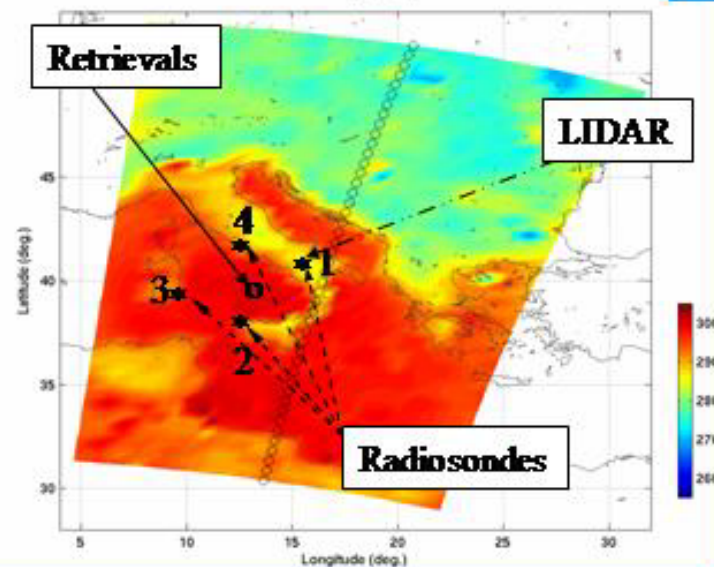
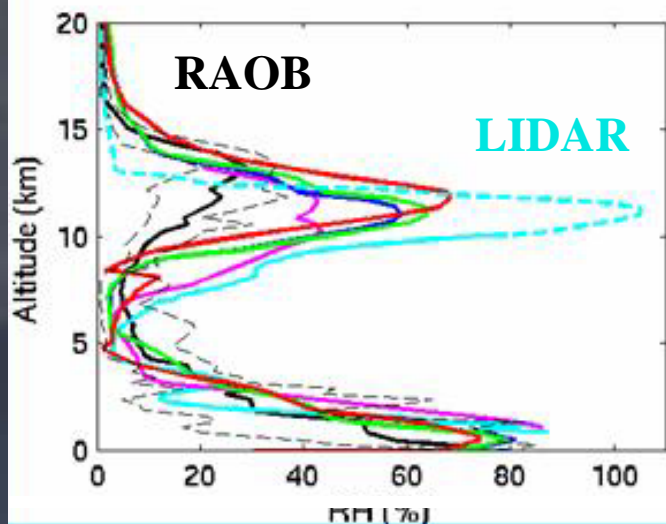
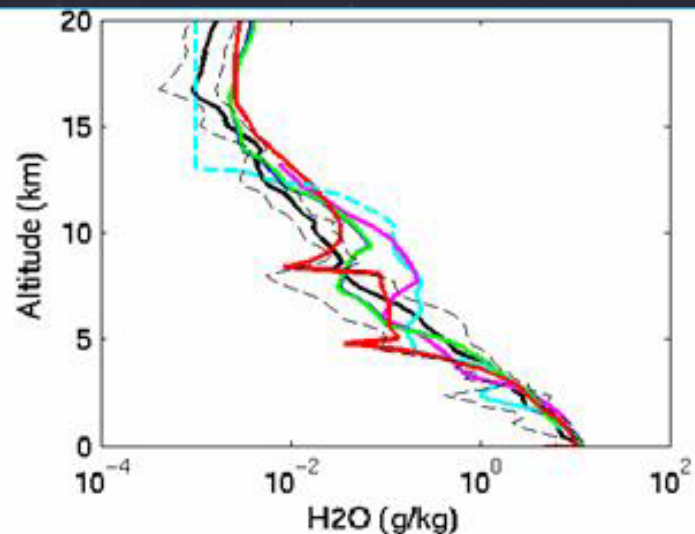
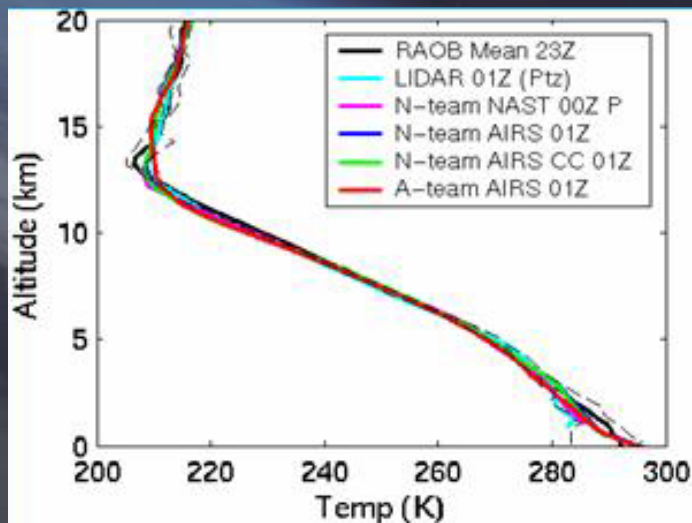
- **IMAA/U of B-DIFA/U of Naples Ground-based Component**

- *Aerosol, Raman, DIAL LIDAR*: Potenza (3) & Naples (1)
- *Radiosondes*: Potenza, Mobile unit, Standard Network
- **Mobile Upward-looking AERI**: 3.0-20  $\mu\text{m}$ , 1.0  $\text{cm}^{-1}$
- **Microwave Radiometer**: 22, 31, 50-60GHz (5  $f's$ )



# EDR (Profile Retrieval) Validations ( Sept. 10, 2004 )

## NAST and AIRS Water Vapor Closer to LIDAR than RAOB





# EAQUATE United Kingdom Cal/Val Campaign

**EAQUATE (European AQUA Thermodynamic Experiment)-**  
*A project to validate radiance and geophysical products obtained by the Atmospheric Infrared Sounder (AIRS) aboard the Aqua satellite*



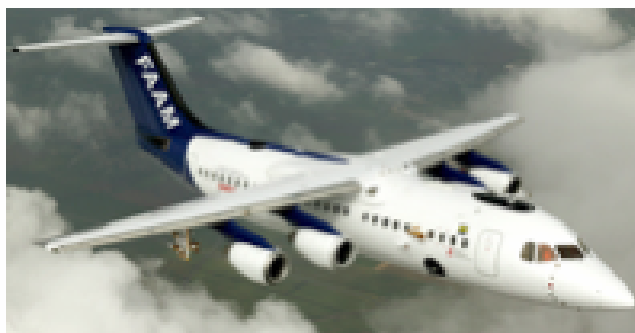
## United Kingdom (Cranfield UK, 12-24 Sept. 2004):

### • US *Proteus* Aircraft



**NAST-I:** 3.6-16  $\mu\text{m}$ , 0.25  $\text{cm}^{-1}$   
**NAST-M:** 50-425 GHz (29  $f's$ )  
**S-HIS:** 3.0-17  $\mu\text{m}$ , 0.50  $\text{cm}^{-1}$   
**FIRSC:** 75-1000  $\mu\text{m}$ , 0.1  $\text{cm}^{-1}$   
 **$\mu$ MAPS:** 4.5-4.9  $\mu\text{m}$ , (3  $f's$ )

### • UK *BaE 146-130* Aircraft

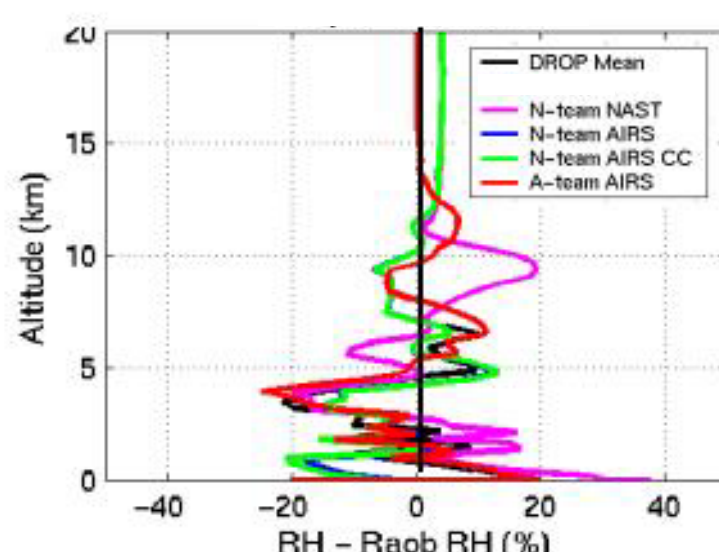
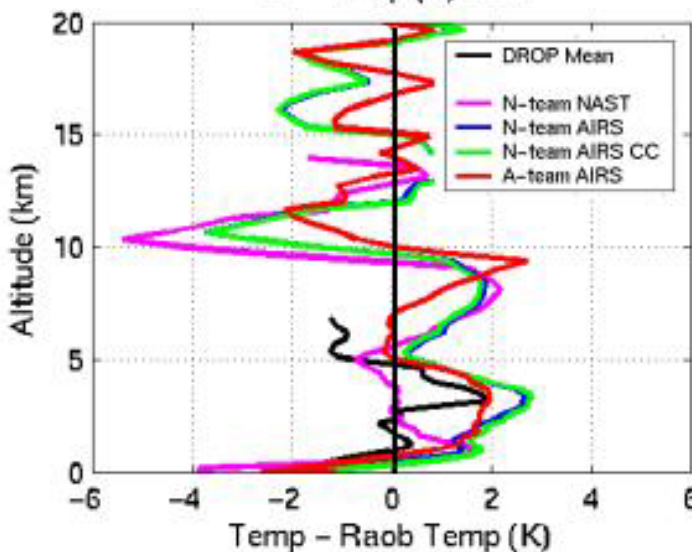
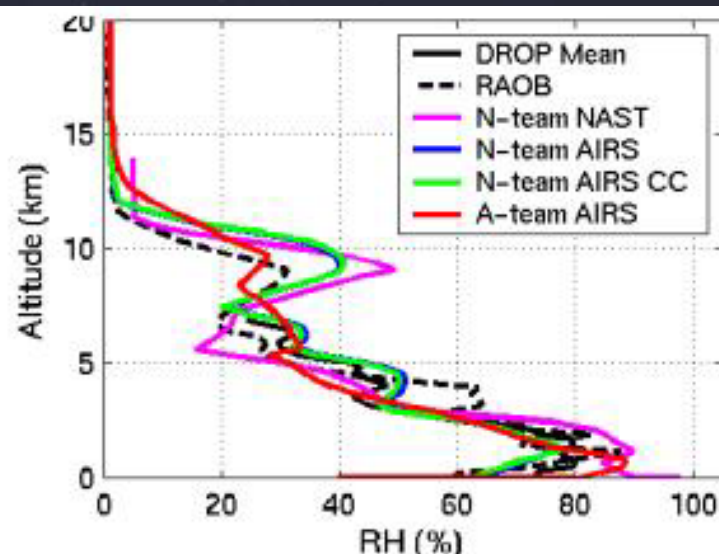
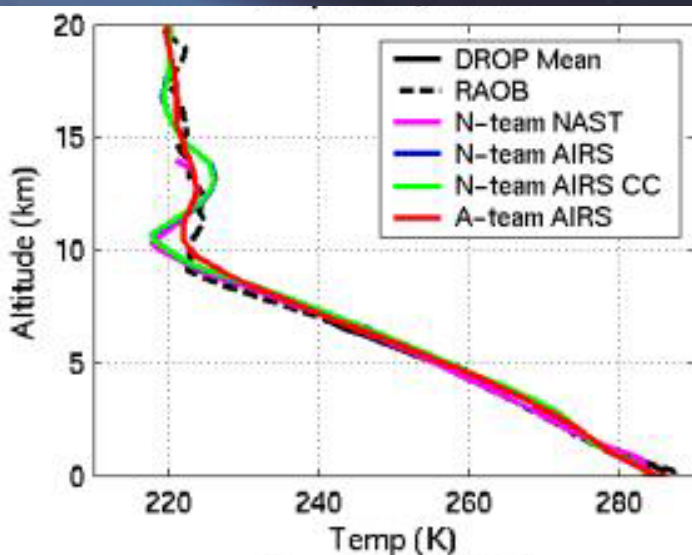


**ARIES:** 3.3-16  $\mu\text{m}$ , 0.50  $\text{cm}^{-1}$   
**DIEMOS:** 23 & 50 GHz (4  $f's$ )  
**TAFTS:** 12.5-125  $\mu\text{m}$ , 0.1  $\text{cm}^{-1}$   
**MARSS:** 89-189 GHz (5  $f's$ )  
**Other:** Drosondes, Outside T, q, V,  
 Chemistry, Radiative Fluxes



# EDR (Profile Retrieval) Validations ( Sept. 14, 2004 )

## NAST Team Algorithm Validates AIRS Science Team Algorithm





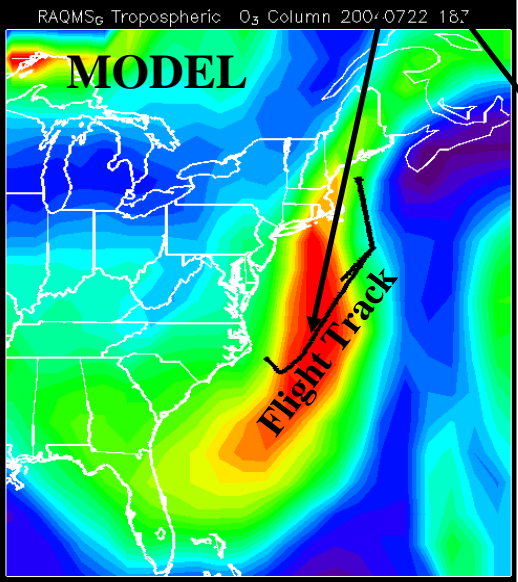
# EDR Validation : Ozone & Water Vapor

Comparison between NAST-I and RAQMS O<sub>3</sub> and H<sub>2</sub>O Analysis July 22, 2004

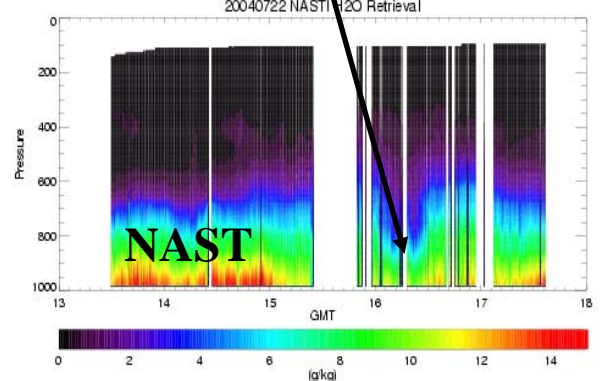
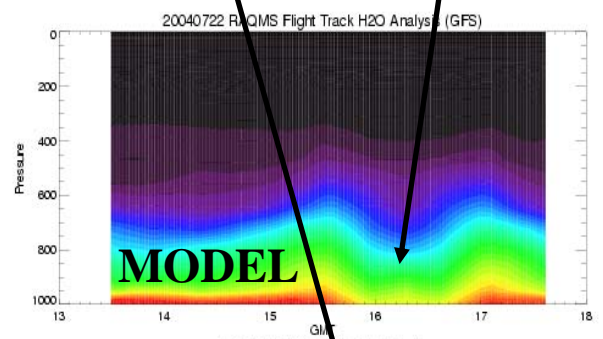
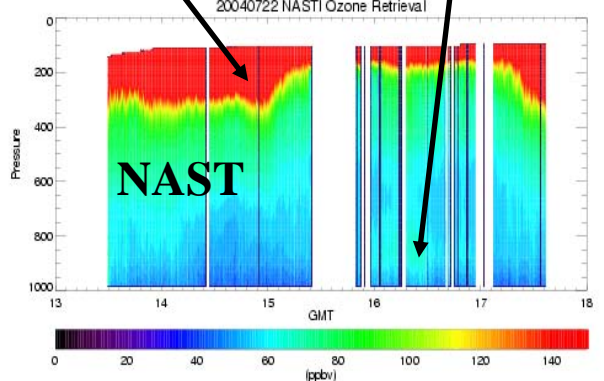
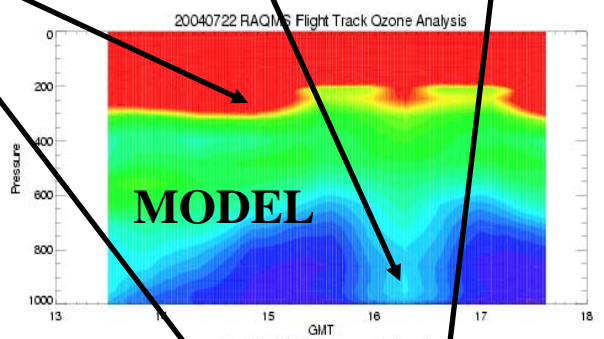
Upper tropospheric  
ozone enhancement

Boundary layer  
ozone enhancement

Moisture Dry  
Tongue



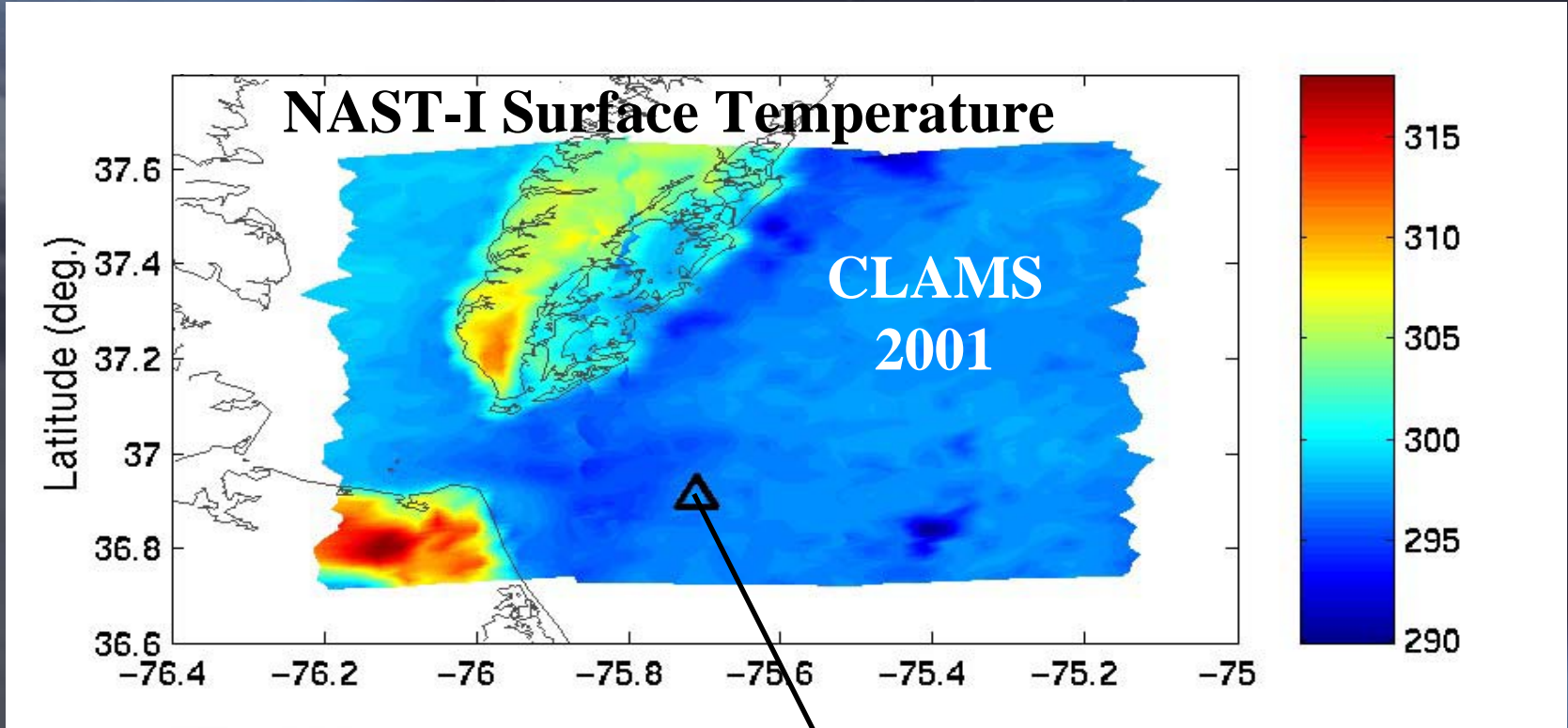
Tropospheric Column O<sub>3</sub> (07/22 18Z)





# EDR Validation :

## Ocean Temperature Can Be Validated to Better than 0.5 C ( < 0.2 C for Skin T )



**NAST  $T_{\text{skin}}$  = 296.9 K**  
**BUOY  $T_{\text{water}}$  = 297.4 K**

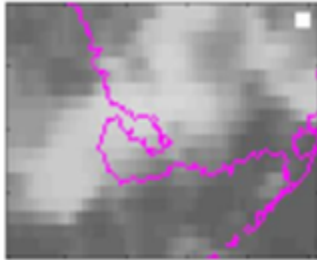
**Difference Due to  
Cool Skin Effect  
(Evaporative Cooling)**

**Validation of Sea Surface Temperature to  $\leq 0.5$  K**

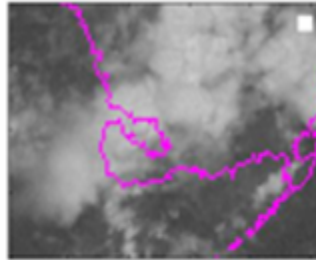


# EDR Validation : Precipitation Validated by NAST-M Based on Comparisons with RADAR

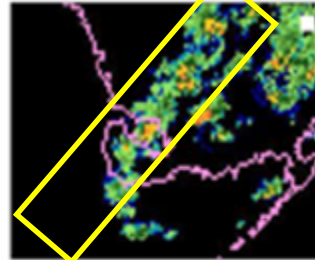
GOES-8  
IR 16:32 UTC



GOES-8  
VIS 16:32 UTC

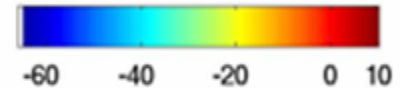


Composite RADAR  
16:45 UTC

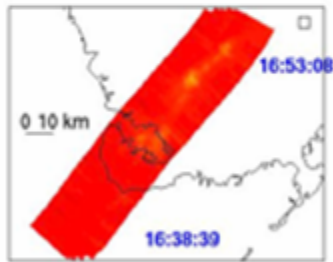


- July 11, 2002 (CRYSTAL-FACE)
- Cruising Altitude at 17 km
- 7.5° antenna beam width (FWHM)
- 1.4 km nadir footprint diameter at height of 7 km
- Swath width of ~30 km at 7 km

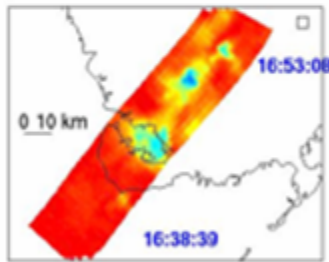
NAST-M Brightness Temp.  
Perturbation [Kelvin]



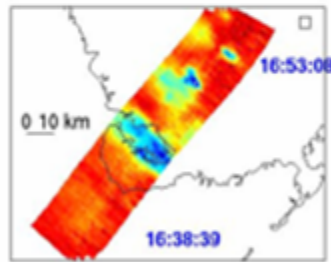
54.200-54.400 GHz



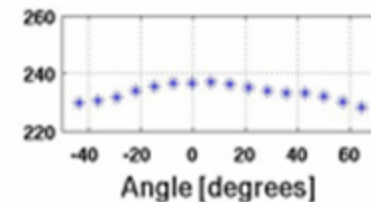
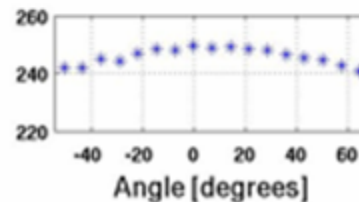
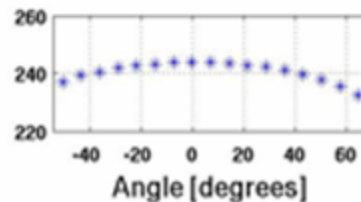
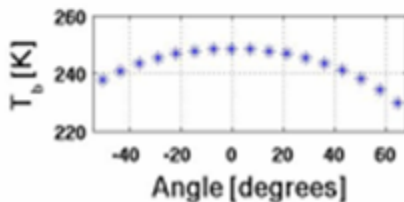
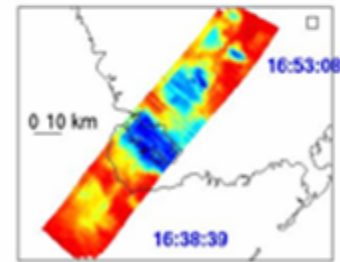
118.75 +/- 1.200 GHz



183.31 +/- 1.0 GHz

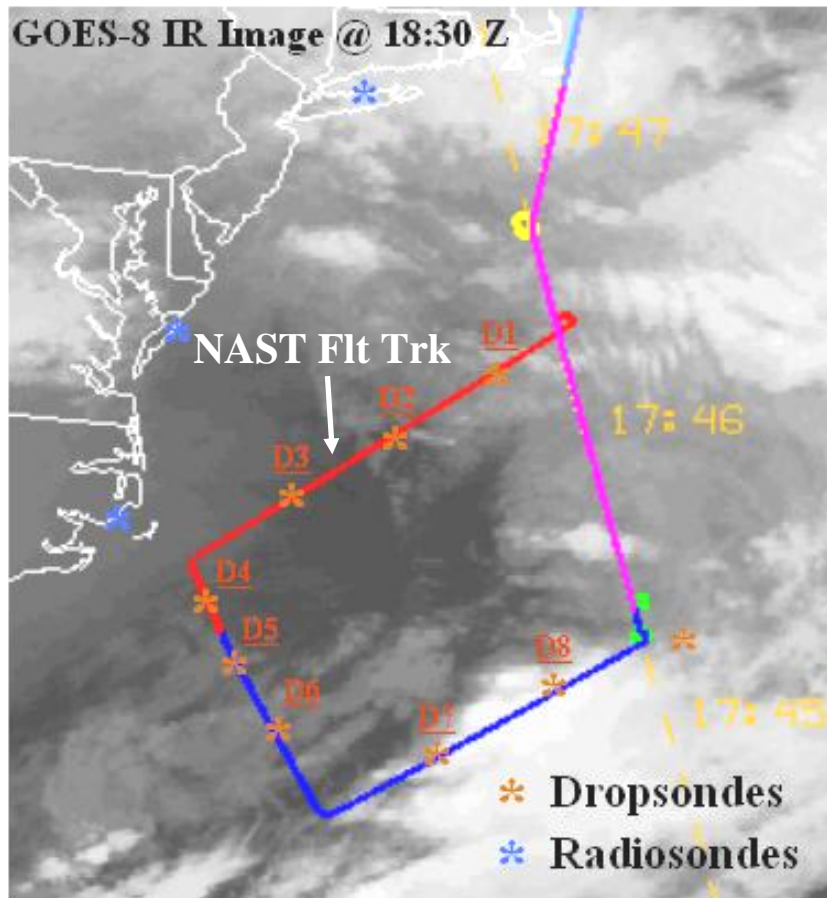


424.76 +/- 2.15 GHz





# Algorithm Validation : NAST Used to Validate An Improved Cloudy CrIS Profile Retrieval Algorithm



## Atlantic THORPEX Regional Campaign (ATReC)

### Cloud Sounding Algorithm Validation (Dec. 5, 2003)

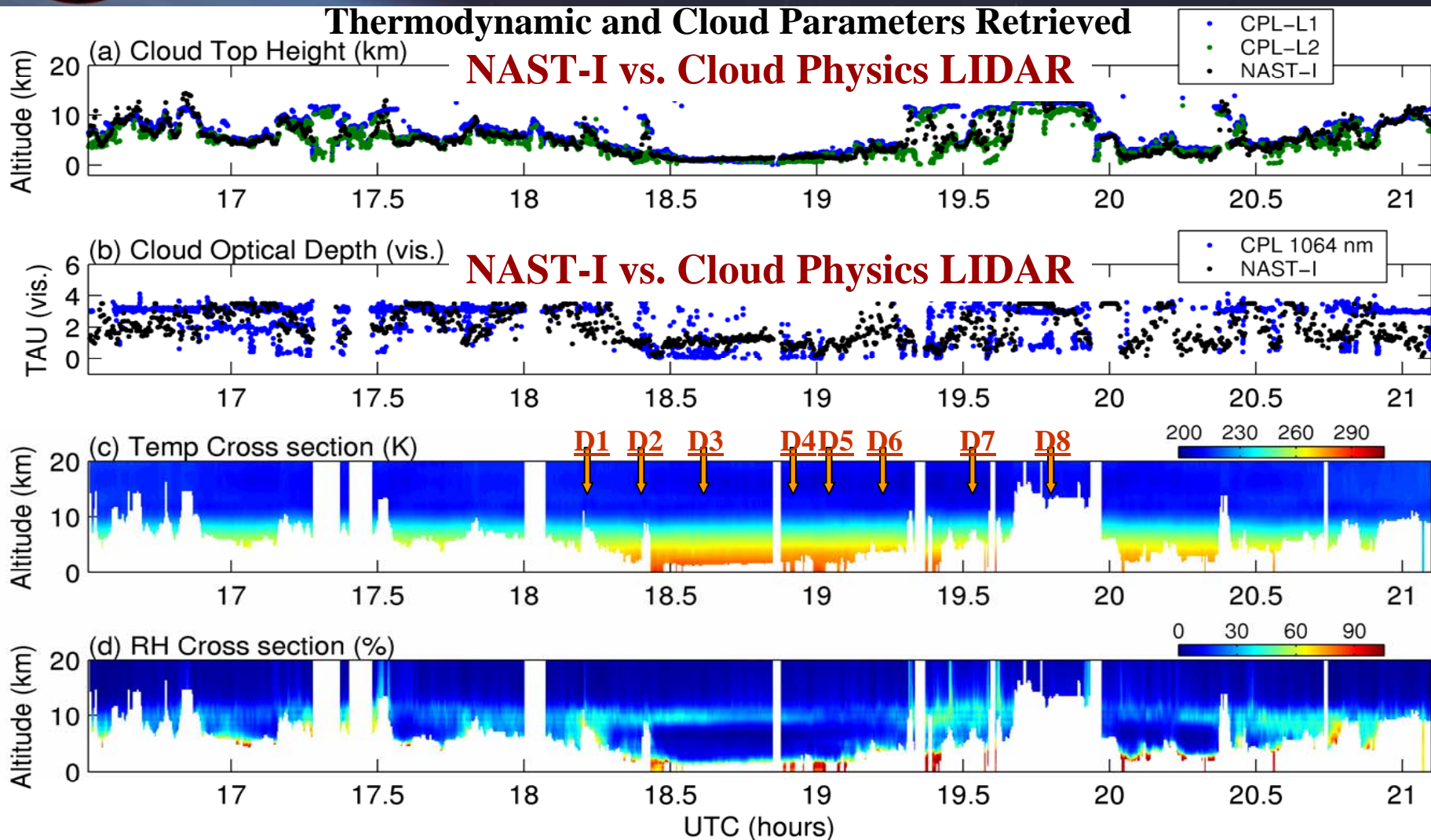
- Dropsonde released from the NOAA G-4 aircraft that flew below the NASA ER-2 aircraft.
- Cloud properties were provided by the nadir-pointing Cloud Physics LIDAR (CPL) on board the NASA ER-2 aircraft.
- IR spectral radiances measured with NAST-I on the NASA ER-2 aircraft.

**Figure:** GOES-8 infrared image shows a variety of clouded conditions; such as medium-level altocumulus, low-level cumulus, thunderstorms, and extensive high cirrus in the region covered by the ER-2 and the G-4. The ER-2 flight track is plotted over the GOES image



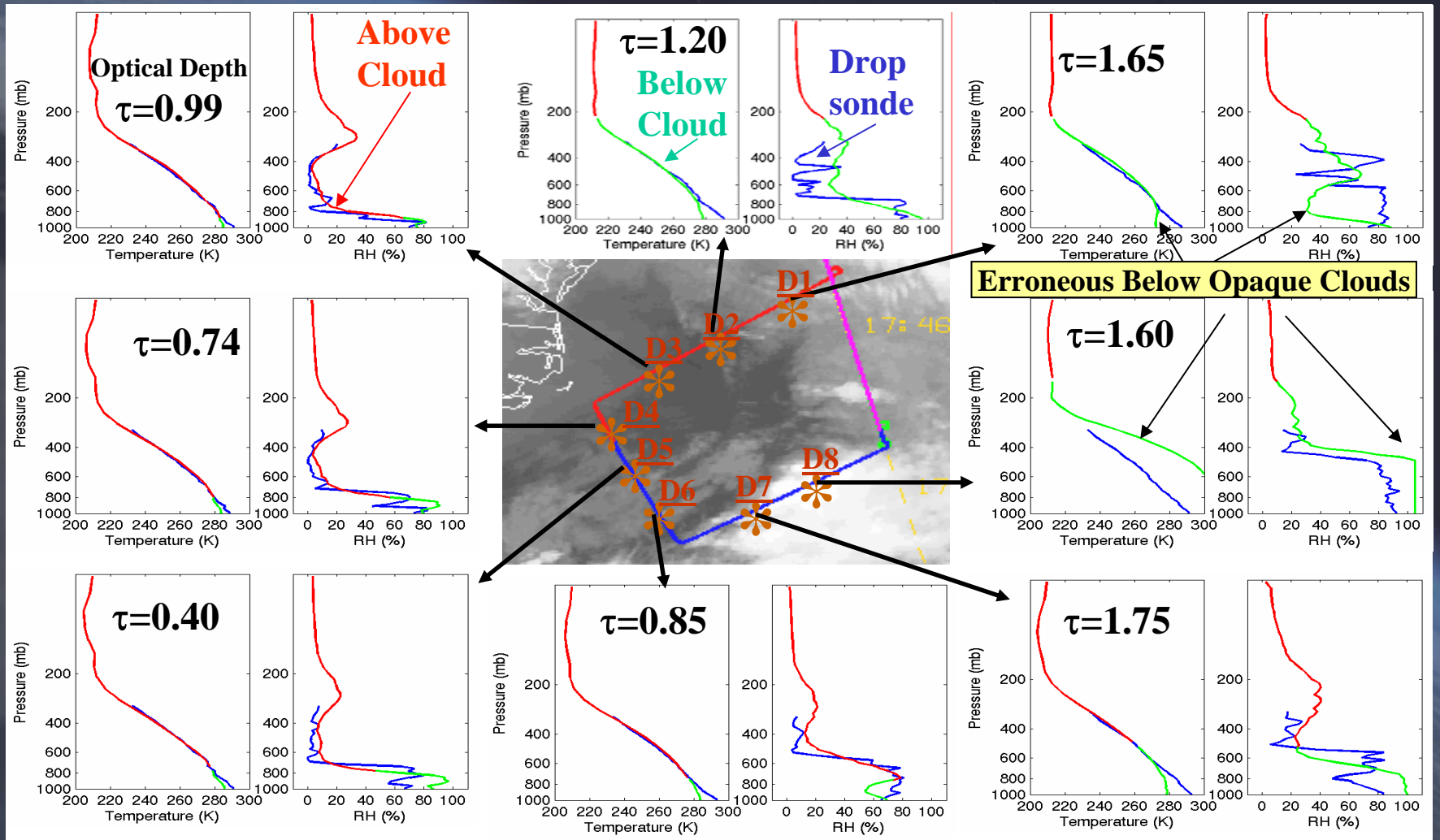
# Algorithm Validation : Improved Retrieval Algorithm Produces Soundings Below Semi-Transparent and Broken Clouds

## Thermodynamic and Cloud Parameters Retrieved





# Algorithm Validation : Comparisons of Individual Dropsondes With Cloudy IFOV NAST-I Retrievals Validate Cloudy Sky Condition Retrieval Algorithm





# Summary and Conclusions

## NPOESS Risk Reduction – NAST for CrIMSS

- A critical calibration/validation resource
- Improved AQUA satellite AIRS/AMSU/MODIS radiances (SDRs), algorithms, and data products (EDRs)
- Validated CrIMSS super fast forward radiative transfer models and cloudy sky profile retrieval algorithms
- Will soon (June 2006) play important role in the calibration/validation and improvement of METOP IASI/AMSU SDRs/EDRs.
- Will enable precision validation of CrIMSS SDRs, Algorithms, and EDRs

